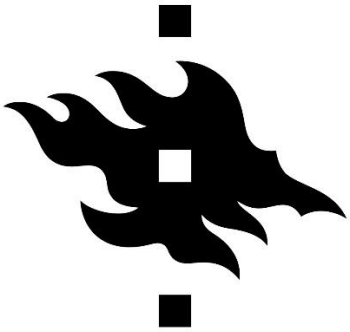

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Plant Biology

RED LIST INDEX AND FUNCTIONAL DIVERSITY FOR FINNISH VASCULAR PLANTS

Jon Rikberg

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Supervisors: Pedro Cardoso & Aino Juslén

Department of Biosciences

Faculty of Biological and Environmental Sciences

UNIVERSITY OF HELSINKI

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Tekijä – Författare – Author
Jon Rikberg

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Tiivistelmä – Referat – Abstract

The Red List Index (RLI) has widely been recognized as a useful tool in keeping track of extinction risk trends of large taxa. The RLI is an index based on IUCN's threat categories. Functional diversity (FD) is a way of measuring biodiversity that describes species´ traits that are linked to species´ ecological roles. In this work I have mapped the spatial distribution of the RLI and functional diversity for Finnish vascular plants.

I first produced species distribution models (SDMs) for all 1194 species of vascular plants in the Finnish Red List 2010 based on records from the Kastikka and Hertta databases and environmental data. A functional tree incorporating 971 of those species was calculated using seven functional traits. The traits that I used were life form, maximum plant height, seed mass, seedbank longevity, life span, specific leaf area (SLA), and leaf dry matter content (LDMC). The trait data was gained from the databases Leda and TRY. Based on the SDMs, the functional tree, and the Finnish Red List, taxonomic and functional diversity and RLI were mapped for the whole of Finland using 10 x 10 km cells. This was the first time FD and RLI were mapped for vascular plant species across Finland. Null models were used to compare observed values with the ones expected if species (and consequently traits) distributions were random accross the country.

Taxonomic diversity (TD) was higher than expected in southern Finland and lowest in northern Finland, suggesting a strong latitudinal gradient. TD correlated with the same environmental variables as FD. Thus, it is likely that both TD and FD are dirven by the same environmental variables. FD was higher than expected in southern and western Finland and lower in the northern and eastern parts of the country. A strong environmental filtering in the north might cause low FD by limiting species´ distributions within many clades and favouring species with similar traits that allow them to survive in extreme conditions. In southern Finland, competitive exclusion might limit the co-existence of species with similar traits, thus increasing trait divergence.

The RLI values were lowest in the Åland islands, along the southern coast, in a few sites in eastern Finland (e.g. Koli and Kuusamo areas), around Kemi and the Gulf of Bothnia and in Kilpisjärvi. Thus, these sites have high concentrations of threatened species. The low RLI sites correspond well with areas with either limestone or dolomite deposits, which explains why many of these areas are floristically unique and present high concentrations of threatened species. In addition, many of the sites with low RLI are geographical extreme areas in Finland, corresponding to the distribution limits of many species. The RLI was high in Ostrobothnia and in large parts of Lapland. In Ostrobothnia, centuries of forest management and a homogenous bedrock and topography have resulted in a vascular plant community based mostly on common species. It is possible, that regional extinctions have happened in Ostrobothnia already before red listing measures began, thus explaining the high RLI values today. On sites with more variety among habitats and bedrock, the RLI values were significantly lower than in the rest of Lapland, suggesting that the high RLI values for parts of Lapland are due to homogeneous plant communities in the northern boreal forests that host only few threatened species.

The spatial distribution of the RLI and functional diversity for vascular plants in Finland were mapped for the first time. A strong latitudinal gradient was found for TD and FD. Low RLI values were found on calcareous soils and on geographic extremes in Finland. To track possible changes in the RLI it would be crucial to remap the RLI in 2019 when the next Finnish Red List is published. A comparision between this work and the remapping based on the 2019 assessment would track changes in the extinction risk across Finland. The current limitation with RLI is that it only considers taxonomic diversity. However, in future work it is possible to incorporate the functional tree used in this thesis into RLI to calculate a functionally weighted RLI.

Avainsanat – Nyckelord – Keywords
red list index, vascular plants, Finland, threat assessment, extinction risk, functional diversity, taxonomic diversity

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Tiivistelmä – Referat – Abstract

Rödlisteindexet (RLI) har allmänt erkänts som ett viktigt redskap när man undersöker utrotningsrisker för stora taxa. RLI baserar sig på IUCN:s hotkategorier. Funktionell diversitet är ett sätt att mäta biodiversitet där arternas olika ekologiska roller beaktas som beror på ekologiska drag. I den här pro gradu-avhandlingen har jag kartlagt rödlisteindexet och funktionell diversitet för Finlands kärlväxter.

Först producerade jag utbredningsmodeller för alla 1194 kärlväxtarter som återfinns in den finska rödlistan från år 2010. Utbredningsmodellerna gjordes på basis av geografisk data från databaserna Kastikka och Hertta samt miljödata. På basis av sju olika funktionella drag gjordes ett funktionellt träd av totalt 971 arter. De funktionella dragen som användes var livsform, växtens maximihöjd, frövikt, fröbankens livslängd, växtens livslängd, speficik bladareal (SLA) och bladets torrsubstanshalt (LDMC). Data om dessa funktionella drag hämtades från databaserna Leda och TRY. På basis av utbredningsmodellerna och det funktionella trädet kartlagdes den taxonomiska och funktionella diversiteten och RLI för kärlväxter för hela Finland. Nollmodeller användes för att jämföra de observerade värdena med förväntade värden ifall arterna (och därmed också de funktionella dragen) skulle ha en slumpmässig utbredning över landet.

Den taxonomiska diversiteten var högre än förväntat i södra Finland och lägst i norra Finland vilket tyder på en stark latitudinell gradient. Funktionell diversitet var högre än förväntat i södra och västra delarna av Finland och lägre i norra och östra Finland. Abiotisk filtrering i norra och östra Finland kan leda till de observerade låga funktionella värdena genom att begränsa arters utbredning och gynna arter med liknande funktionella drag som gör att de överlever också i mer extrema miljöförhållanden. I södra Finland kan intensiv konkurrens mellan arterna ha begränsat arter med likadana funktionella drag, och istället gynnat arter med olika funktionella drag, och på så sätt bidragit till en hög funktionell diversitet.

RLI värdena var lägst i Åland, längs sydkusten, vid ett par ställen i östra Finland (t.ex. Koli och Kuusamo), runt Kemi och Bottniska viken samt i Kilpisjärvi. De här områdena inhyser därmed en stor andel hotade kärlväxter. Områden med låga RLI värden korrelerade med områden med bergsgrund med kalk eller dolomit. Det här förklaras sannolikt av att finländska kalkområden är floristiskt speciella och sådana områden har därför höga koncentrationer av hotade arter. I tillägg visade det sig att många av områdena med låga RLI värden representerade geografiska extremplatser i Finland där många arter lever på sina utbredningsområdens gränser. RLI var högt i Österbotten och i stora delar av Lappland. I Österbotten har decennier av aktivt skogsbruk och en homogen bergsgrund och topografi sannolikt resulterat i kärlväxtsamhällen som främst består av vanliga arter. Det är också möjligt att regionala utdöenden har inträffat i Österbotten redan före man började rödlista arter i Finland vilket skulle förklara de observerade höga RLI värdena för Österbotten idag. I Lappland var RLI betydligt lägre vid områden med en bred sammansättning av livsmiljöer och varierande bergsgrund. Det här tyder på att de höga RLI värden för resten av Lappland sannolikt beror på att de boreala skogarna så här långt norr är rätt homogena livsmiljöer som upprätthåller relativt artfattiga växtsamhällen och därmed har få hotade arter.

För första gången kartlagdes RLI och funktionell diversitet för kärlväxter i Finland. En stark latitudinell gradient observerades för både taxonomisk och funktionell diversitet. Låga RLI värden förekom främst på områden med kalkrik jordmån och även på geografiska extremområden i Finland. För att kunna följa med utrotningsrisken för finska kärlväxter skulle det vara viktigt att göra om samma arbete år 2019 när följande rödlistning publiceras. Då kunde man jämföra resultaten och se i vilken riktning trenden går. Det sätt som RLI används idag beaktar endast taxonomisk diversitet. I kommande studier kunde man dock inkludera det funktionella trädet, som producerades i den här pro gradun, i RLI och således räkna ut ett funktionellt RLI.

Avainsanat – Nyckelord – Keywords

rödlisteindex, kärlväxter, Finland, hotbedömning, utrotningsrisk, funktionell diversitet, taxonomisk diversitet,

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1. INTRODUCTION

Loss of biodiversity is one of the greatest challenges of our time (Hanski 1997). The primary causes to the declining biodiversity are the destruction of ecosystems in natural condition and the degradation and fragmentation of the remaining habitats as a consequence of anthropogenic activity (Vitousek et al. 1997; Pereira et al. 2010; Pimm et al. 2014). As a result of these rapid changes, an increasing number of species face the risk of becoming extinct (Hanski 1997). The trend is also visible in Finland – during the last decades the number of threatened species has increased (Rassi et al. 2010).

The Red List Index has been widely recognized as a useful tool in analyzing trends of threatened species on entire groups (Jones et al. 2011). The Red List Index has been previously calculated for Finnish vascular plants (Juslén et al. 2016) but until today, there has been no studies on where the Red List Index is lowest or highest within Finland. As 16.3% of the vascular plants in Finland are classified as threatened (Rassi et al. 2010) the mapping of the spatial distribution of the Red List Index values across Finland could yield useful information. The current use of the Red List Index recognizes only taxonomic diversity, thus ignoring the species´ different ecological roles driven by different functional traits. Therefore, the mapping of the distribution of functional diversity across Finland could give a better understanding of what factors affect the Finnish flora.

1.1 Finnish Vascular Plants

Vascular plants (Tracheophyta) is the largest group in the plant kingdom and considered to be the most complex group of plants. Vascular plants are characterized by their vascular bundles that transport water and photosynthetic products throughout the plant and are thus well suited for life on land (Rassi et al. 1986). Vascular plants are divided into Lycophytes and Euphyllophytes (Pryer et al. 2004).

There are approximately 308 000 species of vascular plants globally (Christenhusz & Byng 2016). Of these, 3.550 species live in Finland when apomictic species, hybrids and neophytes are taken into account (Kalliovirta et al. 2010). However, only 1.200 of these species are either indigenous or archaeophytes (Kalliovirta et al. 2010). Archaeophytes are species that have

arrived to Finland by the aid of humans a long time ago whereas neophytes have arrived with humans either intentionally or by mistake more recently. The line between archaeophytes and neophytes varies, but in threat assessments in Finland the year 1800 is used as threshold – meaning that in threat assessments species that have arrived before 1800 are considered archaeophytes and species that have arrived after that are considered neophytes (Liukko et al. 2017). Typical archeophytes in Finland are for instance *Allium oleraceum*, *Carum carvi* and *Trifolium pretense* (Hæggström & Hæggström 2010). Examples of neophytes include *Galium album* that spread to Finland during the 19th century and *Impatiens glandulifera* that was introduced to Finland in the 1940s (Hæggström & Hæggström 2010).

Indigenous species on the other hand have occupied Finland without any help from humans. Examples in boreal forests are species like *Pinus sylvestris* and *Vaccinium myrtillum* to name a few (Suominen & Hämet-Ahti 1993; Hæggström & Hæggström 2010). In a historical perspective, all Finnish indigenous plant species are "new-comers" as they all have spread to Finland after the last glacial maximum (Jonsell 2004).

When compared to the rest of Europe, the flora of Finland is rather species-poor (Rassi et al. 1986). The land was covered by ice during the last glacial maximum and the present plant species have spread to Finland during the last 10,000 years after the icecap started retreating (Suominen & Hämet-Ahti 1993). As the flora is so young there has not simply been enough time for speciation to occur. In addition, a lack of topographic elements that would isolate populations in Finland further slows the speciation process, which explains the low number of endemic species in Finland and also partly the low diversity of vascular plants (Rassi et al. 1986; Jonsell 2004). A cold climate, a short growing season, a nutrient-poor soil, a very homogenous bedrock in the whole country and very few calcareous areas all contribute to a relative low diversity of vascular plants in Finland (Rassi et al. 1986; Jonsell 2004).

Human activity increasingly affects vascular plant species occurrences and distributions (Jonsell 2004; Ryttäri et al. 2012). Some species are being favored and their distribution range is growing, whereas for other species the opposite is true; their populations are declining and their distribution ranges are shrinking. As a result of lost habitats, degradation of remaining habitats, fragmentation and other environmental changes, the extinction risk for hundreds of vascular plants has risen and they are considered to be threatened or near threatened (e.g. Rassi et al. 2001; Rassi et al. 2010; Ryttäri et al. 2012, Juslén et al. 2016).

1.2 Assessment of threatened species

Threatened species are species that have declining populations or very small and restricted populations and thereby have an uncertain future and could be in the danger of becoming extinct. In Finland, threatened species have been assessed in 1985, 1991, 2000 and 2010. The next red list will be published in 2019 (Rassi et al. 2010; Tiainen et al. 2016). In Finland, threatened species have been assessed according to a classification system by the International Union for Conservation of Nature (here after IUCN) since 2000 (Rassi et al. 2001; Westling 2015). The publication of these red lists (the threat assessments) allows tracking the probability for species to become extinct and to follow the long-term changes of entire groups (Rassi et al. 2010; Westling 2015).

The different red list categories correspond to different extinction risks for the assessed species (IUCN 2012; Brito et al. 2010). If the species belongs to a high-risk category it means that the probability for the species to vanish over time is high (Rassi et al. 2010). It does not affect the threat assessment if a threatened species originally has been abundant or rare (Westling 2015). Instead, species are red listed on a basis of which criteria they fulfill according to given criteria (IUCN, 2012). These criteria include several population characteristics, for instance how fast the species population is declining during a certain period of time, how big (or small) the distribution range is and how probable it is that the species could go extinct during a certain period of time (Rassi et al. 2010; IUCN 2012; Ryttäri et al. 2012). Based on these criteria the species can be assessed into 11 different categories (Fig. 1) of which 9 have been used in the Finnish red lists (Rassi et al. 2010; Liukko et al. 2017).

The IUCN criteria emphasize reduction of population size, how big or small the species´ geographic range is, how big the population is and how fast it is declining. A species must not fulfill all criteria to be classified as threatened, already if one criteria is met the species is considered threatened (Liukko et al. 2017). For a summarized version of the IUCN criteria, see Supplementary Table 1.

If there have been no observations for a longer period of time of one single individual of a certain species and it can be assumed that the last mature individual of the species has died, and the species is categorized as extinct (EX). If the species on the other hand, has disappeared from the wild but individuals still live in cultivation in for instance zoos or cultivation, the species is

categorized as Extinct in the Wild (EW). The categories EX and EW have not been used in Finland, but instead the category Regionally Extinct (RE) was used when it was certain that the last reproductive individual had died in the country (Rassi et al. 2010; IUCN 2012).

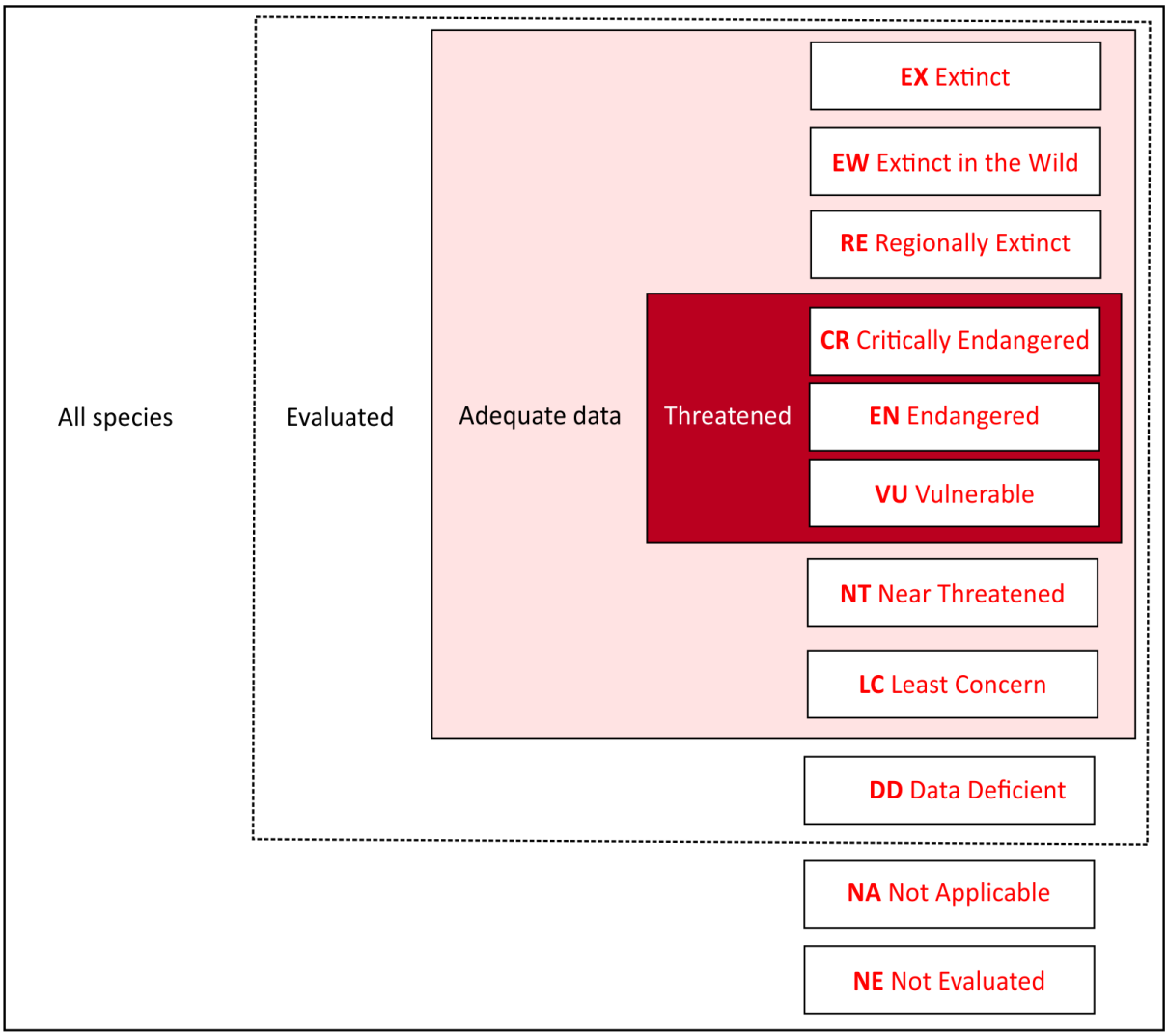

FIGURE 1. The IUCN categories. The categories EX and EW have not been used in the Finnish red lists. Modified from Rassi et al. (2010).

Threatened species are species that possess a significantly high risk of extinction and can be categorized into three categories; Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) (Figure 1). If the species does not fulfill any of the criteria for VU (Supplementary Table 1) but some of the criteria are close to being fulfilled or can be assumed to be fulfilled in the near future, the species is categorized as near threatened (NT). Species that are not even close to fulfill the criteria are categorized as Least Concern (LC) and are thus not considered to be at risk of extinction (Rassi et al. 2010).

Some species have been assessed that are so poorly known that there simply is not enough information about the state of the population, geographic range and potential threats to it to be able to determine extinction risk. These species are categorized as Data Deficient (DD) (Rassi et al. 2010).

The category Not Applicable (NA) is used for species that have spread to Finland after the year 1800 (neophytes) as the IUCN guidelines state that the threat classification should only be applied to wild populations inside their natural range (IUCN 2012, Mannerkoski & Ryttäri 2007). Neophytes do not meet these requirements and are correspondingly classed as NA (Not Applicable) in the Finnish Red List (Rassi et al. 2010, Liukko et al. 2017). In addition, species that have spread to Finland by themselves are categorized as NA until they are established and have reproduced at the area for a certain period of time (usually at least for 10 years) (Liukko et al. 2017).

Species that have not been assessed at all belong to the category Not Evaluated (NE). Typically, this category includes species that were a priori left out due to the lack of expertise (Rassi et al. 2010). In the Finnish red list apomictic vascular plants like *Hieracium* spp., *Pilosella* spp. and *Taraxacum* spp. are classed as NE (Liukko et al. 2017).

1.3 Threatened vascular plants in Finland

In Finland, there are approximately 3550 vascular plant species. The Finnish red list 2010 assessed 1206 taxa (Rassi et al. 2010). Of these, 197 were classified as threatened (VU, EN or CR) and further 122 taxa as Near Threatened (Table 1). In total, ca. 16% of the assessed vascular plants are threatened. If the Near Threatened species are included the number increases to 26% (Ryttäri et al. 2012).

TABLE 1. Number of vascular plant taxa by threat category in the Finnish red list 2010 (modified from Rassi et al. 2010).

Threat category	RE	CR	EN	VU	NT	DD	LC	NA	NE
Vascular plants	6	31	88	78	122	9	872	717	~ 1630

The largest single factor that contributes to the increasing extinction risk of vascular plants in Finland is overgrowing of pastures and meadows (Rassi et al. 2010; Ryttäri et al. 2012). Grazing has been shown to create and maintain a high biodiversity among vascular plants on pastures (e.g. Oldén & Halme 2016). At the end of the 18th century it is estimated that the total area of pastures and meadows in Finland was 1.6 million hectares (Soininen 1974). Today however, only a fraction remains and of the 43 different types of rural biotopes, 93% are considered threatened (Schulman et al. 2008). As a consequence of lost habitat (meadows turned into fields) and degradation of the habitats that are left (overgrowth caused by both lack of grazing or moving and atmospheric nitrogen deposition) it is not surprising that the primary threat for 36% of Finland´s threatened vascular plants is overgrowing of rural biotopes (Rassi et al. 2010). For example, *Botrychium simplex* (CR), *Campanula cervicaria* (VU), *Galium verum* (VU) and *Primula farinosa* (EN) are species that have suffered from overgrowth and loss of rural biotopes such as different meadow types (Kypärä 2012; Laine 2012; Lindgren 2012; Ryttäri & Väre 2012). Some species that have adapted to open rural habitats have found refugia in railway embankments, roadsides and small airfields. These new habitats have become increasingly important for many exdangered taxa. They are rather similar to more traditional meadows and pastures as they are usually sun-exposed, subject to contant disturbance and are often being mowed, which favors smaller vascular plants typical of open rural biotopes. Even if these areas cannot replace the enormous amount of lost rural habitat area, their importance in maintaining species populations should not be underestimated (Rassi et al. 2010).

Nonetheless, overgrowing is not only a problem for traditional rural biotopes but also for other open landscapes like fells and beaches. In particular, alien species like *Lupinus polyphyllus* (NA) and *Rosa rugosa* (NA) pose a threat for many native vascular plants as they are aggressive competitors and large-sized and can therefore cause overgrowth (Ryttäri et al. 2012). In northern Lapland in the fells, overgrowth occurs as the tree line moves upwards as a response to a warmer climate (Rassi et al. 2010).

Changes in the mire landscape, namely draining of mires and peat mining, is the primary threat for 12% of the threatened species (Rassi et al. 2010). Especially in Southern Finland, the mire species have declined as over 75% of the mires have been drained (Raunio et al. 2013). Further, intensive forest management is the primary threat for 10% of the threatened species (Rassi et al. 2010).

The ongoing climate change is already affecting the Finnish flora and is expected to become an even greater threat in the future. At present, it is mostly vascular plants in the fells and on seashores that are affected by climate change (primary threat for 6% of the threatened species) (Rassi et al. 2010; Ryttäri et al. 2012). Some vascular plants in the far north of Fennoscandia have adapted to a cold climate into such extent that their metabolism simply cannot function in a warmer climate. Species that have adapted to cold conditions usually have functional traits that help them survive the harsh environmental conditions. When the climate changes these traits become unsuitable or cease to offer a competitive advantage and thereby increasing the danger of extinction (Körner 2012; Ryttäri et al. 2012). In the fells, climate change causes overgrowth as the alpine treeline moves upwards. As the climate warms up, species have to move north or to higher altitudes. For example, *Ranunculus glacialis* (NT) lives on a very restricted area in the Kilpisjärvi region, meaning it cannot escape north (inside the borders of Finland) and neither can it escape to higher altitudes as it already lives on the highest fells in Finland (Rassi et al. 2010).

Conclusively, the Finnish vascular plants are threatened by rapid ecosystem changes caused by human activity that has led to loss of habitats, fragmentation and degradation of the habitats that remain. For many species, small population size and fragmentation in itself make them vulnerable. As a matter of fact, very narrow geographic range or extremely small population size are the primary concern for 13% of the threatened species, making them the second largest single threat factor for Finnish vascular plants (Rassi et al. 2010). Small population size and narrow distribution range are problems for a number of reasons. Statistically, it is more probable that a small population disappears than a large one due to unpredictable events such as genetic drift (Aapala 2001b). For several vascular plants in Finland this is a problem; their small and isolated populations might be relatively stable today but might perish in the near future (Aapala 2001a; Aapala 2001b; Hanski & Ovaskainen 2002; Rassi et al. 2010; Ryttäri et al. 2012).

According to Aapala (2001a) some Finnish vascular plants are threatened to become locally extinct in the long run if the circumstances in the habitat do not improve, with extinction debt across several habitat types in Finland (Hanski & Ovaskainen 2002). Hanski & Ovaskainen (2002) explain extinction debt as a time lag where the populations of species have not yet reacted to changes in their habitats and as a result the populations can be expected to decline in the future. If habitat loss has been extensive the new equilibrium state for many species is local

extinction. Thus, the actual extinction event is being postponed into the future and an extinction debt has been created (Hanski & Ovaskainen 2002).

1.4 Red List Index

The Red List Index is widely accepted as a valuable tool in conservation biology (Jones et al. 2011). It is a tool that illustrates how the extinction risk across many species proceeds over time for a certain set of taxa or for a certain area if species have been assessed at least twice (Butchart et al. 2004; Butchart et al. 2006; Butchart et al. 2007; Juslén et al. 2013; Juslén et al. 2016). The Red List Index is based on national or international red lists and is thus based on the same IUCN categories as discussed earlier. Importantly, the Red List Index only takes into account so called genuine changes (i.e. changes caused by actual changes in the extinction risk) in the red list (Butchart et al. 2006; Butchart et al. 2007).

In the Red List Index, each threat category is weighted differently (Table 2). For all species that are examined the threat score is summed based on their threat category. Then it is divided by 5 (value for "worst case scenario": all species extinct) and divided by the number of examined species. The result is subtracted from 1 and as a result, the Red List Index varies from 0–1. If all examined species are LC then the index is 1 and if the index is 0 it means that all species are extinct (Butchart et al. 2007).

TABLE 2. The weightings for each threat category for the calculation of the Red List Index.

Threat category	Weight
Least Concern (LC)	0
Near Threatened (NT)	1
Vulnerable (VU)	2
Endangered (EN)	3
Critically Endangered (CR)	4
Extinct (EX)	5

The Red List Index has been calculated for Finnish vascular plants twice. The Red List Index for year 2000 was 0.894 and year 2010 it was 0.884 (Juslén et al. 2016). Since the index value

has declined it means that the overall trend is negative; between 2000 and 2010 the extinction risk for vascular plant species has risen. For comparison, in 2010 the Red List Index for vascular plants was 0.873 in Sweden (Gärdenfors 2010) and 0.905 in Spain (Saiz et al. 2015). As at least two threat assessments are required to calculate the Red List Index (to be able to compare dates) it has so far been calculated for vascular plants only in a handful of countries (Saiz et al. 2015).

The Red List Index cannot only be calculated for sets of species but also for different geographical areas or habitats as Juslén et al. (2016) suggested. Practically, the Red List Index can be viewed as a sort of a summary of the red list that can be used as basis for policy making (Butchart et al. 2004; Martín-López et al. 2009; Juslén et al. 2016).

1.4.1 Limitations of the Red List Index

Taxonomic diversity is by far the most studied dimension of biodiversity. Since the Red List Index is based on individual red list assessments, it uses the same demographic data as threat categorization. Only the species demographies are under focus when evaluating the species extinction risk and thus also the Red List Index. However, biodiversity can be measured in more than one way (e.g. Lyashevska & Farnsworth 2011; Stegen & Hurlbert 2011).

Taxonomic diversity disregards the ecological and functional roles of species, based on their functional traits (Stegen & Hurlbert 2011). In other words, the Red List Index does not take into account functional diversity. As the Red List Index can be used as a tool in species conservation, it is reasonable to ask whether we are protecting the right species if we only take taxonomic diversity into account. Is there a risk that certain species with unique functional traits might vanish unnoticed in an aggregate index such as the RLI? This is a crucial question, as the red lists tend to steer the resources when it comes to conservation biology (Butchart et al. 2004; Martín-López et al. 2009).

1.5 Functional diversity

According to Lindborg & Eriksson (2005) there is an ongoing discussion whether the current threat assessments based on species could be replaced by functional assessments. These functional assessments would be based on traits directly linked to ecosystem functioning (e.g.

Lindborg & Eriksson 2005; Stegen & Hurlbert 2011). Functional traits include different physiological and morphological characters like growth forms, life span, reproductive values, and leaf size and are often associated with the species´ competitive ability (Weiher et al. 1999).

Functional traits are often associated with ecological aspects of plant communities and affect both community structure and species diversity (Weiher et al. 1999; Westoby et al. 2002; Johansson et al. 2011). Several studies have shown that there are trade-offs between various plant functional traits like seed number and seed size (Smith & Fretwell 1974; Stearns 1991; Venable 1992). Particular plant traits are often linked to particular habitats as a result of adaptation to the habitat in question (e.g. Cornelissen et al. 2003; Duncan et al. 2011). Therefore, functional diversity might be a more comprehensive way of describing plant communities than taxonomic diversity alone (Flynn et al. 2011).

As environmental conditions change it might change the ratio of plant traits, some traits might be lost at the same time as other traits are being favoured (Duncan et al. 2011). Further, loss of habitat and fragmentation may threaten species differently depending on their specific traits (Dupré & Ehrlén 2002). Therefore, there might be a link between threatened species and which traits they possess (Kolb & Diekmann 2005).

There has been found several traits that affect how plants cope with changes in their environment (e.g. Leach & Givnish 1996; Duncan & Young 2000; Murray et al. 2002; Williams et al. 2005; Fréville et al. 2007; Bernhardt-Römermann et al. 2011; Duncan et al. 2011; Marini et al. 2012; Hedwall & Brunet 2016; Schellenberger Costa et al. 2017). For instance, according to Weiher et al. (1999) seed production, clonal ability, disturbance avoidance and plant longevity are important factors affecting the persistence of plant species in a community. Other traits, such as an annual life cycle, dispersal by animals and a competitive ability for light, have also been associated with persistence when habitat loss accrues (Marini et al. 2012). Further, a study in the Czech Republic found that critically endangered plant species tend to be weak competitors compared to common species (Gabrielová et al. 2013).

Some of these traits are important when assessing threatened vascular plants, as for instance some mire species might persist on a drained mire for decades through vegetative regeneration or simply because the plants life span is long (Aapala 2001a; Lindholm & Heikkilä 2006). In the example above the functional traits vegetative regeneration and the life span might help the

species to persist on the drained mire. If the drained mire later is restored the impoverished populations of vascular plants might bloom from the few individuals that have persisted on the mire (Uusitalo et al. 2006). How long threatened species can live in changing habitats is therefore an important question as all habitats today are undergoing rapid changes because of anthropogenic activity (Vitousek et al. 1997; Pereira et al. 2010; Pimm et al. 2014).

As there has been found several links between traits and extinction risk, disturbance response, habitat loss and persistence, comparing traits between common species and threatened species could yield useful information that can be used for the conservation of threatened vascular plants (Lahti et al. 1991; Murray et al. 2002). Since functional diversity might be a more comprehensive way of describing plant communities and plant's response to disturbance, it would be crucial to incorporate the functional dimension of biodiversity into the threat assessments to ensure that no ecologically unique functional group disappears if species go extinct.

1.6 Spatial patterns of biodiversity

Species richness or taxonomic diversity is distributed unevenly across the globe (e.g. Kerkhoff et al 2014). Patterns in species richness have puzzled scientists for centuries. von Humboldt (1808) argued that species diversity is high in the tropics and decreases as one moves towards the poles and further suggested that temperature could explain these patterns. In other words, von Humboldt (1808) proposed a mechanism that explains species richness gradients across the globe. Later, the wonders of the tropics were described by Darwin and Wallace and several others as species diversity of the tropics was something that moved ecologists to unravel the patterns of species diversity at large scales (Brown 2014). There has been plenty of different models trying to explain the latitudinal gradient (e.g. Grime 1975, Tilman 1982; Mittelbach et al. 2001**)** but no consensus has arisen. The latitudinal gradient theory has gained large support even if there still are many unanswered questions regarding what actually causes the gradient (e.g. Brown 2014; Kerkhoff et al. 2014).

If there is a similar latitudinal gradient in the spatial distribution of functional diversity has been under far less attention (for spiders, see Cardoso et al. 2011). Studies have shown (e.g. Meynard et al. 2011) that functional diversity tends to follow the same spatial patterns as taxonomic and

phylogenetic diversity. Thus, a latitudinal gradient affecting the spatial distribution of functional diversity could well be true.

1.7 Aims of the study

This master's thesis assesses 1197 vascular plant species or all vascular plants assessed in the Finnish Red List 2010 with the exception of category Data Deficient (DD). The red list contains all indigenous species and archaeophytes in Finland. In the red list appears 1206 taxa in total, mostly species, but also subspecies and varieties (Rassi et al. 2010). When threat category Data Deficient (DD) is excluded the number of assessed taxa with sufficient data is 1197 (Supplementary Table 2. Nomenclature in this thesis is consequent with the one in the Finnish Red List and thus follows Hämet-Ahti et al. (1998).

With the help of species distribution models, the aim of this study is to map and understand the different dimensions of diversity and extinction risk of Finnish vascular plants. The first objective of this thesis is to map the vascular plant taxonomic and functional diversity across Finland. Functional diversity is measured on the basis of selected functional traits for most species native to the country. I then try to find the causes to the spatial distribution of the functional diversity of vascular plants in Finland.

The second objective of this thesis is to map the (taxonomic) Red List Index for all native Finnish vascular plant species across the country and to identify the areas with the lowest Red List Index values. The areas with lowest Red List Index values are the areas with highest concentration of threatened species. I also try to find a cause for the observed distribution of the Red List Index.

To my knowledge, none of the two objectives have been tried before for any Finnish taxon.

2. MATERIAL AND METHODS

2.1 Distribution Data

Thanks to effective monitoring we have relatively good knowledge of the Finnish vascular plants (Kalliovirta et al. 2010). Nonetheless, there are deficits in the known distributions of the group in Finland. The most comprehensive vascular plant distribution data is to be found in Kastikka [Atlas of Finnish vascular plants] – a database maintained by the Unit of Botany at the Finnish Museum of Natural History LUOMUS.

The Kastikka presence data consists of a grid of 10 x 10 km cells spanning over the whole Finland. Naturally, some of these cells have been assessed more thoroughly than others. For instance, in the northern parts of Lapland there are some cells with no recorded vascular plants at all (Fig. 2). Several cells also reportedly only have 0-50 species in it, although it is very unlikely that this would actually be the case. These cells are only so remote, or the terrain is so difficult (wet mires for instance) that no one has recorded any species from there yet or if data collection has been made it has only been made for a small section of the cell or is otherwise incomplete.

Similarly, close to cities (especially university cities) the species diversity is often very high. This pattern is mostly explained by the fact that in rural and urban areas there might be hundreds of neophytes and a broad variety of habitats that together increase the diversity (Figure 2). Additionally, cells close to cities are also easy to access and have therefore been more effectively recorded. It can also be assumed that, at least to some degree, there is an underrepresentation when it comes to very common species as it is time consuming to record all species and it might be considered "boring" to record species that occur "everywhere". Some taxa might not be recorded as their identification is considered difficult (e.g. members of the genus *Carex* and family Poaceae) Nevertheless, the contributors responsible for the vast majority of the records in Kastikka are mostly botanists (Lampinen & Lahti 2016). Although the Kastikka database surely includes errors, it is still the best data available and in international comparison Finland has very good knowledge of its vascular plants and their distribution (Kalliovirta et al. 2010). Therefore, I see fit to use it in this thesis.

All distribution data was extracted from the database by R. Lampinen in January 2017. Nomenclature in this thesis is consequent with the one in the Finnish Red List and thus follows Hämet-Ahti et al. (1998). For threatened species I gained distribution data from the Hertta database from the Finnish Environment Institute (SYKE) as they monitor the threatened species and thus have more precise distribution data for the threatened species than the Kastikka-database. The data from the Finnish Environment Institute has also been the basis of the plant distribution maps in the book "Suomen Uhanalaiset Kasvit" [Threatened Plants of Finland] (Ryttäri et al. 2012). Three taxa had to be excluded due to insufficient data. This meant that I had 1194 taxa in total (Supplementary Table 2).

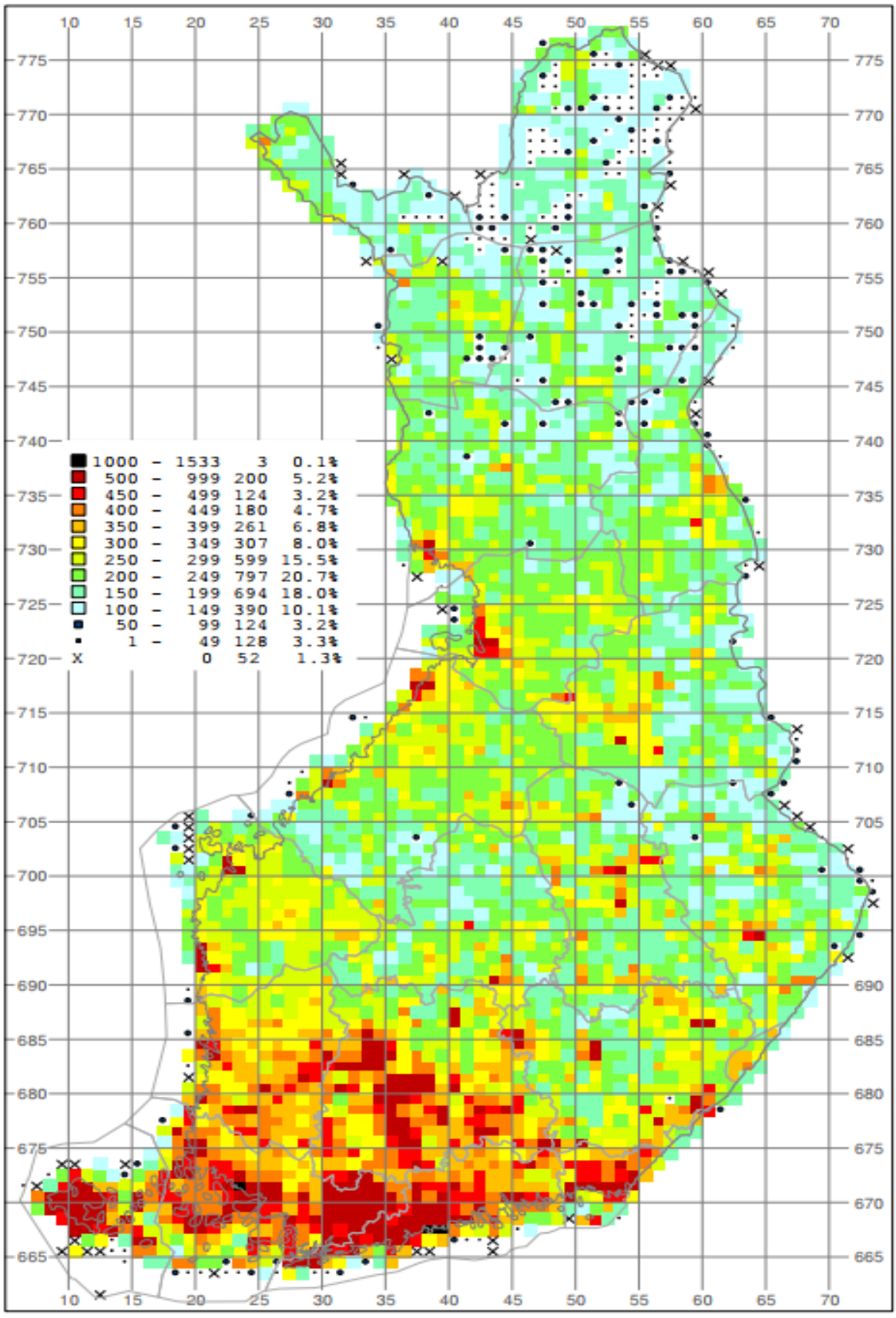

FIGURE 2: Number of vascular plant species in each cell (10 x 10 km). The numbers after the class are how many cells and percentage of total amount of cells there are of each class (Lampinen & Lahti 2016).

2.2 Species distribution models

Some of the problems with the Kastikka data discussed earlier can be avoided by modeling the data to fill the gaps necessarily existing in the database. By doing this, some obvious sampling errors are avoided. For instance, those cells with no species recorded (Fig. 2) will be rectified as the SDM most likely will predict which species might be present there based on environmental variables and those species that have been recorded from neighboring cells. The cells with no records have most likely very similar environmental conditions as the adjacent cells that have records. Thus, it is likely that the SDM will "fill" the no record cells with the same species that inhabit the neighboring cells, unless of course, there are some actual dissimilarities in the environmental conditions that could result in a different species composition.

Species distribution models (SDMs) are tools that on the basis of environmental information predict species distributions across landscapes (e.g. Heikkinen et al. 2006; Elith & Leathwick 2009). To run a successful SDM one needs both accurate species abundance or occurrence data and environmental data that is relevant for the species distribution so that the model will be able to predict where the species has adequate conditions to live. SDMs compare the similarity of the conditions at all sites where the examined species occurs. On the basis of the environmental conditions, the algorithms then estimate the potential species distribution which is de facto based on the probability that the species occurs on a given site depending on if the environmental conditions seem to match the known presences (Elith & Leathwick 2009). This is possible as species tend to present more or less strict but always limited environmental condition on which they are able to survive (Pearson & Dawson 2003: Heikkinen et al. 2006; Elith & Leathwick 2009). However, there are several reasons why the species might not be present at sites suggested by a SDM. These models usually ignore species interactions (competition is often an important factor that limits species distributions) and geographic barriers that limit species distributions (Pearson 2008). Nevertheless, SDMs are useful tools in ecological work (e.g. Pearson 2008; Elith & Leathwick 2009).

When simulating species distributions, climate is widely considered to be the most important factor at broad spatial scales (e.g. Pearson & Dawson 2003). Climatic variables are consequently the most commonly used variables in SDMs (Pearson 2008). Yet, according to several studies (e.g., Heikkinen et al. 2007; Luoto 2007; Eskildsen et al. 2013), SDMs predict

species distributions more successfully if land cover data is included in the simulation. In this thesis I'm using both climatic variables and land cover data.

The environmental data I used was elevation, 19 different climatic variables and 13 different forms of land cover data. The elevation and climatic data (Table 3) was gained from Worldclim (http://www.worldclim.org/bioclim) (Fick & Hijmans 2017). The data was accessed on April 6th 2017.

TABLE 3. Bioclimatic variables used in the species distribution modelling (Fick & Hijmans 2017).

Shortening	Bioclimatic variable
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

The Corine land cover data was gained from the Finnish Environmental Insitute (http://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot) on April 5th, 2017. Corine land cover data has frequently been used in SDM: s (e.g. Storch et al. 2003; Titeux et al. 2009; Heikkinen et al. 2012; Heikkinen et al. 2014). The Corine land cover data consisted of 48 different land cover layers (Table 4). 48 different land cover layers were considered to be

unnecessarily specific for the thesis so we merged the layers into 13 classes (Table 5) to make the analysis easier and avoid overfitting. The data was then transformed into raster files in the same grid of 10 x 10 cells, as the species distribution data. This was done in the R 3.1.2 environment (R Core Team 2014). The grid consisted of a total of 8733 cells.

TABLE 4. The original 48 different classes of land cover (Finnish Environment Institute, 2017). Some of the classes have the same new name as there are several different classes of some land cover types. The full names of all classes are available on the Finnish Environment Institute website (in Finnish only).

Class	Name of layer
1	Continuous urban fabric
2	Discontinuous urban fabric
3	Commercial units
4	Industrial units
5	Road and rail networks and associated land
6	Port areas
7	Airports
8	Mineral extraction sites
9	Mineral extraction sites
10	Dump sites
11	Construction sites
12	Sport and leisure facilities
13	Sport and leisure facilities
14	Sport and leisure facilities
15	Sport and leisure facilities
16	Non-irrigated arable land
17	Fruit trees and berry plantations
18	Pastures
19	Pastures
20	Land principally occupied by agriculture, with significant areas of natural vegetation
21	Agro-forestry areas
22	Broad-leaved forest
23	Broad-leaved forest
24	Coniferous forest
25	Coniferous forest
26	Coniferous forest
27	Mixed forest
28	Mixed forest
29	Mixed forest
30	Natural grassland
31	Moors and heathland
32	Transitional woodland/shrub

33	Transitional woodland/shrub
34	Transitional woodland/shrub
35	Transitional woodland/shrub
36	Transitional woodland/shrub
37	Beaches, dunes, and sand plains
38	Bare rock
39	Sparsely vegetated areas
40	Inland marshes
41	Inland marshes
42	Peatbogs
43	Peatbogs
44	Salt marshes
45	Salt marshes
46	Water bodies
47	Water bodies
48	Sea and ocean

TABLE 5. The 13 merged layers that were used in the species distribution modelling. The second column shows which original land cover classes (Table 4) that were merged into the new 13 classes. All original layers, except layer 48 (sea and ocean) were used.

New Class	Old classes	Name of merged layer
1	1–11	Urban areas
2	12–15	Urban green areas
3	16–19	Arable land and pastures
4	20–21	Agro-forestry areas
5	22–23	Broad-leaved forest
6	24–26	Coniferous forests
7	27–29	Mixed forests
8	30–31	Natural grasslands, moors, heathland
9	32–36	Transitional woodland / shrub
10	37–39	Beaches, dunes, bare rock, sparsely vegetated areas
11	40–43	Inland marshes, peatbogs
12	44–45	Salt marshes
13	46–47	Fresh water bodies

Usually, species are dispersal limited. If the SDM finds a suitable site for the species but it is unrealistically far away from the rest of the distribution area it is unlikely that the species will actually be present there. This is a factor that was also taken into account by using latitude and longitude as two additional variables.

2.2.1 Mapping threatened and very common species

The distribution of the threatened species was not modelled as the data received from SYKE is considered to be highly reliable we can assume that the species are occurring only on the known sites. Even if there most likely are some cases where some threatened species occur on unknown sites it would still not allow for a simulation because most threatened species have a very narrow range and only occur on a limited number of sites. A simulation would not necessarily recognize this and because of the good quality of the data I would risk predicting the presence of species where they are not in fact present. Very common species, present in over 65% of the cells, were not simulated as their distribution was found to be close to complete and unnecessary to predict.

These two groups of species that were not modelled, either rare or very common, were mapped with function `map.points` in the r package red (Cardoso 2017). All maps were checked manually to ensure that no errors had accrued and were compared to the maps in Ryttäri et al. 2012.

2.2.2 The Modelling

For all other species, species distribution modelling was done in the R-environment with function `map.sdm` of the package red. Package red is a package for both spatial analysing and Red List Index measures. The advantage with using red in species distribution modelling is that it uses maximum entropy (maxent). One of the biggest problems with species distribution models are that usually, as in this thesis, the only data that is available is presence data. This means that the SDM is being built from data describing where a species is present but it lacks all information on sites where the species do not occur – absence data (Phillips et al. 2006). However, maxent needs only presence data to interpret the most likely distribution range of a species. In addition, maxent recognizes the species´ core distribution (based on sites with most suitable conditions) and grades down the disitrubion when going towards sites with less suitable conditions. Thus, there will not be any sharp, unnatural lines in the distribution of the species between suitable and unsuitable sites (Phillips et al. 2006; Cardoso 2017).

I tested the code for the species distribution model several times with different set of species and later with all species in the thesis before doing the final simulation to make sure that the code worked as it was supposed to. The full codes can be found in the Appendices.

When R had successfully ran all 1194 species the SDMs were manually checked with maps created without simulation (only presence points on a map) to see that they made sense. I checked that the SDMs did not over- or underestimate any species distributions and that they took dispersal limits into account.

2.3 Red List Index

2.3.1 Calculating the RLI

First, to know which species were present in each cell, I used the SDMs and the species distribution maps I created earlier. I produced a matrix with all cells in the grid with the information which of the 1194 species were present in each cell. The code is found in the Appendices.

When I knew which species were present in each cell I could move to the next step; calculating Red List Index values for each of the cells based on which species are present in the cells and then create a map that illustrated the Red List Index values across Finland.

2.3.2 Analysing the results

I tested if the observed Red List Index values were correlated with altitude, the bioclimatic factors or the land cover layers used in the species distribution modeling process.

To be able to examine whether the observed Red List Index values were higher or lower than expected by chance alone I used a null model. Null models are used to test whether an hypothetical driver of a given pattern can be attributed to chance or found to be significant with a given probability. Null models randomize the data sets in defined ways and have become increasingly popular in ecological studies (e.g. Raes & ter Steege 2007; Swenson 2014).

I checked the Red List Index results by doing a null model of the expected distribution of the Red List Index values. The null model redistributed and randomized all species but kept the species richness at the original level at all sites. The null model ran for 999 times. To inspect the result, I then created a map that showed the difference between the expected Red List Index values ("Red List Index by chance alone") and the observed Red List Index values (Red List Index based on the method described earlier).

The expected distribution of the Red List Index can be used to calculate an effect size that might be used to test the statistical significance of the deviations from expectation. Highly positive effect sizes indicate that the difference between observed and expected Red List Index values are higher than expected by chance and highly negative effect sizes indicate the opposite (Swenson 2014). I calculated the effect size, scaling from 0-1, for the map that illustrated differences between the expected and observed Red List Index values. The effect size was calculated based on the percentile of the observed value in relation to the distribution of null model values. The codes for this process is found in the Appendices.

I also drew a map showing the sites of the lowest Red List Index areas across Finland and limestone or dolomite deposits. This map was produced in Corel Draw. I used a bedrock map obtained from the Geological Survey of Finland and imported it, together with the Red List Index map into Corel Draw as two separate layers. Then I produced a third layer, choosing only certain elements (low Red List Index areas and limestone or dolomite bedrock sites) and combined them into a new map.

2.4 Functional diversity

2.4.1 Functional traits

I surveyed the ecological literature for research that linked plant functional traits to extinction risk, disturbances in their habitats and studies that compared traits between rare and common species to find traits that could be relevant for my thesis. In total, 52 published research papers were surveyed. On the basis of the literature and with the help of the traits check list by McIntyre et al. (1995) I chose 7 traits from the LEDA database (Kleyer et al. 2008). Additionally, I also used the TRY database (Kattge et al. 2012) in cases where there was missing data in the LEDA database. These traits are, 1) life form, 2) maximum plant height, 3) seed mass, 4) seedbank

longevity, 5) life span, 6) specific leaf area (SLA), and 7) leaf dry matter content (LDMC). The traits are handled below along with their descriptions and assumed associations to extinction risk, disturbance, habitat loss or other relevant factors.

The trait life form is originally based on Raunkiaer's (1934) classification system, in which the plants are classified according to where their perennating parts are in aspect to the ground. The life forms are often seen as examples of adaptation to climate (Cornelissen et al. 2003). For instance, on the highest fells in northern Lapland in Finland, few or no species have their perennating buds high above ground where they would be fully exposed to wind and freezing temperatures (Cornelissen et al. 2003, Mossberg & Stenberg 2003). Additionally, life form characteristics are strongly linked to how species persist on disturbed sites (McIntyre et al. 1995; Bernhardt & Römermann et al. 2011). Plants with their buds a little bit above the ground, like chamaephytes and young phaneropyhtes, are more sensitive to trampling than species with their buds close to ground (for instance rosette plants) or geophytes with their buds below ground (Raunkiaer 1934; Liddle 1975; Cole 1995).

In this thesis I followed the life forms used in the LEDA database which are a combination of Raunkiaer's system and other specialised morphological forms (Kleyer et al. 2008). The LEDA database recognizes 11 different life forms. However, in my data I only had species belonging to 8 life forms (Table 6).

TABLE 6. The 8 different life forms used in this thesis. The traits as they are defined by Cornelissen et al. (2003) and Kleyer et al. (2008).

Life form	**Location of perennating tissue**	**Description**
Phanerophyte	> 0.5 m	Plants that grow taller than 0.5 m and whose shoots do not die during the unfavourable season. Mostly trees and shrubs.
Chameophyte	< 0.5 m	Plants that do not grow taller than 0.5 m or that grow taller than 0.5 but die periodically during the unfavourable season.
Hemicryptophyte	ground surface	Periodically dies back to remnant shoot system, many grasses (*Poaceae*).
Geophyte	below ground	All parts above ground die during the unfavourable season. Storage organs below ground.
Hydrophyte	under water	Aquatic plants.
Therophyte	seed	Annual plants that complete their life cycle in one year.
Liana	-	Grows as a liana (specialised morphological form).
Vascular semi-parasite	-	Partly parasitic plant (specialised morphological form).

In total, 533 species were missing in the life form data from the LEDA database. Information about the missing species was gained from the TRY database (Kattge et al. 2011) and literature (Hämet-Ahti et al. 1998; Mossberg & Stenberg 2003; Ryttäri et al. 2012). For subspecies and varieties, I used the information given for the corresponding species if information for the subspecies was missing.

By definition, plant height is the distance between the base of the plant and highest photosynthetic tissue usually expressed in metres (Cornelissen et al. 2003). For aquatic plants the part of the stem that is located under water is included in the height (Cornelissen et al. 2003). Plant height is linked to various trade-offs for how plants cope with environmental stress (Cornelissen et al. 2003) and a study in the Czech Republic showed that critically endangered vascular plant species had a lower plant height than other species (Gabrielová et al. 2013). Other studies have showed that smaller vascular plants are more heavily affected by fragmentation (Marini et al. 2012). Further, Johansson et al. (2011) found a positive correlation between plant

height and persistence which indicates that taller plants have a higher likelihood to persist for long periods of time on the same site.

In the LEDA database there were multiple records of maximum plant height for each species so I calculated average values of the original measurements. For the 475 missing species in the database, maximum height records were gained from Mossberg & Stenberg (2003) and Hämet-Ahti et al. (1998).

Seed mass has been associated with both plant species´ survival in fragmented habitats and to how prone the species is to go extinct (Leach & Givnish 1996; Duncan & Young 2000; Kolb & Diekmann 2005; Fréville et al. 2007; Duncan et al. 2011). The seed mass is the average value of the oven- dry seed mass of a given species (Cornelissen et al. 2003). In the seed mass data 553 species were missing. For these I calculated the mean index value from the genus. If the whole genus was missing it had to be excluded. For some missing fern species, I calculated the genera's mean value from Gómez-Noguez et al. (2016) as several fern genera were missing in the LEDA data.

Most vascular plants have seed banks that help them persist in the habitat (Lindborg 2007). The seed bank longevity data consists of measurements of how long a species seed can be viable in the soil (Kleyer et al. 2008). To illustrate the longevity, an index ranging from 0-1 can be used (Table 7). In the data from LEDA there were usually several measurements per species. I used the mode to get only one index value per species. For missing species (in total, 595 missing species) in the data I calculated the mode index value from the genera. Some missing genera had to be excluded altogether.

TABLE 7. Seed Bank Index (Kleyer et al. 2008).

Seed Bank Index	Description
0	Transient, species with seeds that persist in the soil less than one year.
0.5	Short term persistent, species with seeds that persist in the soil for at least one year, but less than five years.
1	Long-term persistent: species with seeds that persist in the soil for at least five years.

In the seed longevity data 595 species were missing. I used average values of the genera for missing species. Some genera had to be excluded due to missing data for whole genera. For subspecies and varieties, I used the information given for the corresponding species if information on the subspecies was missing.

The average life length of a plant is called plant lifespan (Kleyer et al. 2008). Longer plant life span can help the species persist on disturbed locations (Aapala 2001b; Johansson et al. 2011). On the basis of Kleyer et al. (2008) I used two categories; annuals and perennials. Annuals are species that complete their life cycle in one year whereas perennials live for more than one year (Cornelissen et al. 2003). Some species can have both values; sometimes in some habitats the species is an annual but sometimes a perennial (Kleyer et al. 2008). For the trait plant lifespan 631 species were missing from data gained from the LEDA database. Values for the missing species were taken from Mossberg & Stenberg (2003) and Ryttäri et al. (2012) and in some cases assumptions based on other species in the same genera were made for missing species. For subspecies and varieties, I used the information given for the corresponding species if information on the subspecies was missing.

I also chose two leaf traits: specific leaf area (SLA) and leaf dry matter content (LDMC). According to Cornelissen et al. (2003) SLA is "the one-sided area of a fresh leaf divided by its oven-dry mass". High SLA values enable the plant to maximize light capture and species with high SLA usually grow rapidly and have short-lived leaves thus having a fast return on the leaf production. High SLA species have a strategy where they invest little in the production of leaves but the leaves do not withstand physical damage (i.e. wind, herbivory) particularly well. On the other hand, species with low SLA values tend to have a different life strategy. They grow slowly, have long-lived leaves that withstand physical damage better than the leaves by high SLA species, and therefore these species have a slow return in their investment in leaf production (Poorters & Bongers 2006). According to Cornelissen et al. (2003) habitats with little resources often have species with low SLA whereas habitats that are rich in resources often have species with higher SLA values.

The other leaf trait, LDMC, is defined as "the oven-dry mass of a leaf divided by its water-saturated fresh mass" by Cornelissen et al. (2003). LDMC corresponds to the same life strategies as SLA but the strengths of these correlations are usually weaker than for SLA. High

LDMC species typically invest more in their leaves as they have tough leaves that withstands physical damage better than species with low LDMC (Cornelissen et al. 2003).

For the leaf traits SLA and LDMC I calculated average values for all species based on LEDA measurements and for missing species I calculated the average value for the whole genera and used that value instead. For SLA 525 species were missing and for LDMC 581 species. For LDMC I used measurements of the leaf without the petiole and rachis simply because there were more records than for the "whole" leaf including the petiole and rachis. Some genera had to be excluded due to missing data for whole genera.

2.4.2 Functional diversity

According to Petchey & Gaston (2002) the calculation of functional diversity can be divided into four steps. The functional traits that functional diversity is based on needs to be in a matrix and has to be transformed into a distance matrix (distances between species). Further, the distance matrix needs to be clustered into a dendrogram and the last step is to calculate the branch lengths of the dendrogram. Based on the branch lengths, functional diversity of a given community can easily be calculated. These steps can easily be achieved in the R-environment (Swenson 2014).

All traits were combined into a matrix consisting of species names and each trait in one column. I only used species that had no functional trait info missing. This meant that I could analyze a total of 971 species of the original 1194 in the thesis (Supplementary Table 2). In total, I had four quantitative traits (SLA, SDM, plant height and seed bank index) and two categorical traits (plant life span and life form).

This excel-file was imported to R and with packages vegan and cluster coded into a dendrogram using the traits. The traits were weighted differently. The quantitative traits were each given the weight of 1. Categorical traits were coded into binary dummy variables and the weight of each was inversely proportional to the number of options (0.125 for each of eight options within plant form). With the functions hclust and daisy I created a dendrogram (see the code in the Appendices). I used function cut to cut the branches of the dendrogram to be able to more carefully examine the result (Fig. 3).

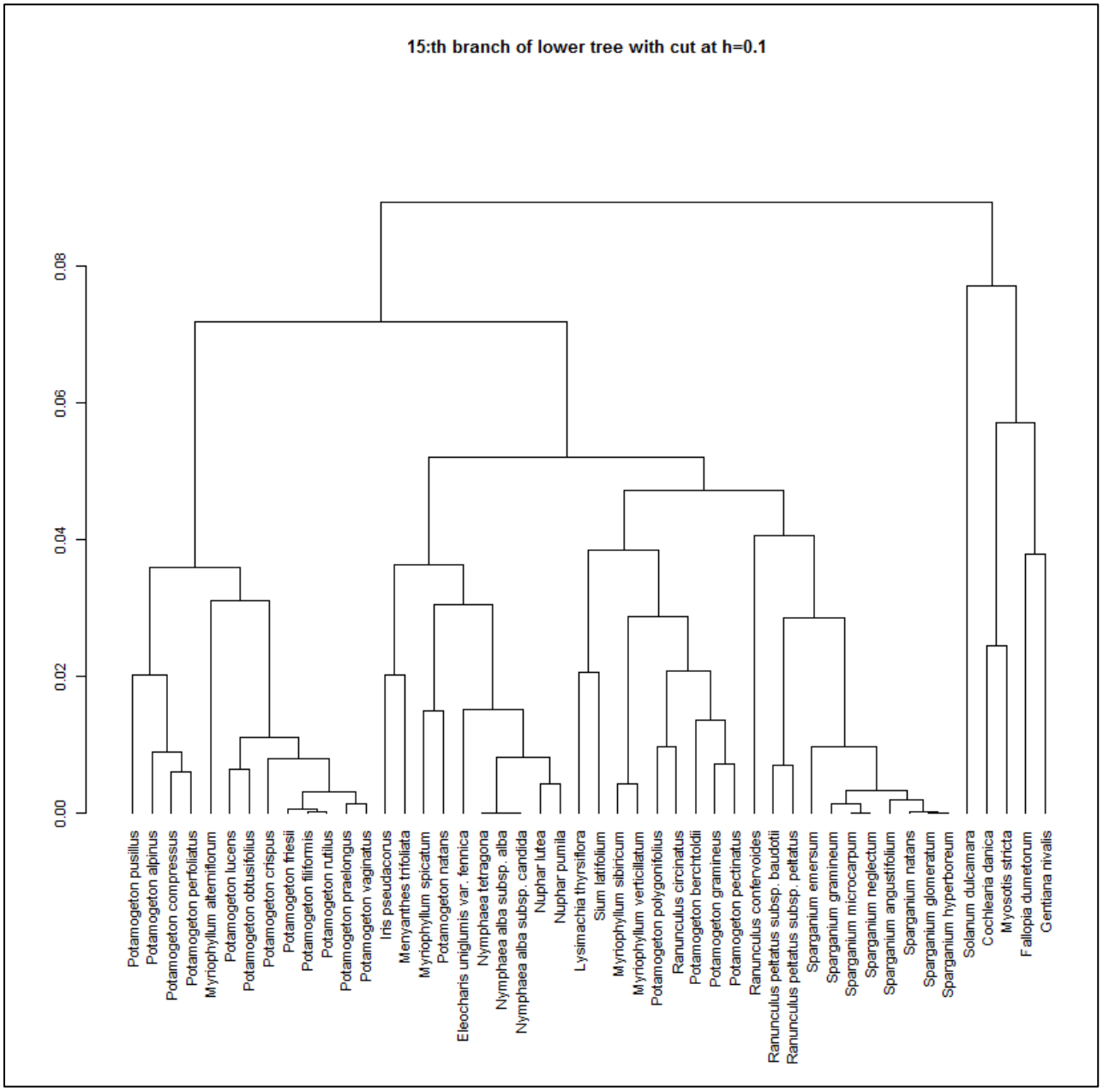

FIGURE 3. A small part of the dendrogram showing branches with many aquatic plants (for instance *Potamogeto*n sp., *Myriophyllum* sp., *Nymphae* sp. and *Sparganium* sp.).

After having checked that the functional tree looked reasonable to the best of my knowledge, I started to calculate the functional diversity. This process can be divided into three steps: extracting which species are present in each cell, calculating the functional diversity for each cell and create a map of the functional diversity.

The first step was to find out which species are present in each cell. To know which species are present in each cell I used the SDM: s and the species distribution maps I created earlier. I used function `stack` to stack all the maps (raster files) together and started analyzing them. I made a `for` loop to go through all cells one by one. This produced a matrix with all cells in the grid with the information which of the 971 species were present in each cell. The code is found in the Appendices.

Next, I calculated functional diversity values for each of the cells based on which species are present in the cells. The functional diversity values were gained by using the dendrogram (Fig. 3) I created earlier. To be able to confirm that there were no errors with the coding process I did a test run with only six species. I plotted a functional tree of them and then calculated the functional diversity for each cell and then I mapped the functional diversity. I then calculated manually the distances between the species from the functional tree and compared it to the map. If there would have been some errors in the coding process then the manually calculated functional diversity values and the map, created based on the functional diversity values R gave me, would not have matched. However, this was not the case as they matched perfectly. When I was sure that the code was working I repeated the process but with all 971 species. I calculated the functional diversity values for each cell and then I mapped them (see codes in the Appendices). As a result, I got a map of the functional diversity across the whole Finland.

I checked the functional diversity results by doing a null model of the expected functional diversity under the condition to be able to see if there are any cells that have higher or lower functional diversity than expected if all species contributed equally to the tree". The null model ran for 999 times. To inspect the result, I then created a map that showed the difference between the expected functional diversity ("functional diversity by chance alone") and the observed functional diversity (functional diversity based on the method described earlier). This map was called "diffmap" [difference between expected and observed functional diversity].

The expected distribution of the functional diversity can be used to calculate an effect size that tests the statistical significance. High effect size indicates that the difference between observed and expected functional diversity is higher than expected by chance and a low effect size indicates the opposite (observed diversity is lower than expected by chance) (Swenson 2014). I calculated the effect size, scaling from 0-1**,** based on the percentile of the observed value in relation to the distribution of null model values.

Further, I also tested whether functional diversity was correlated to any of the environmental layers I used in the species distribution modelling. The codes for this process is found in the Appendices.

2.5 Biogeographical provinces of Finland

In the results and discussion sections of this thesis I refer to 21 biogeographical provinces of Finland. For further information regarding the provinces, see for instance Hämet-Ahti et al. (1998) or the Finnish Biodiversity Info Facility (www.laji.fi).

3. RESULTS

3.1 Taxonomic diversity

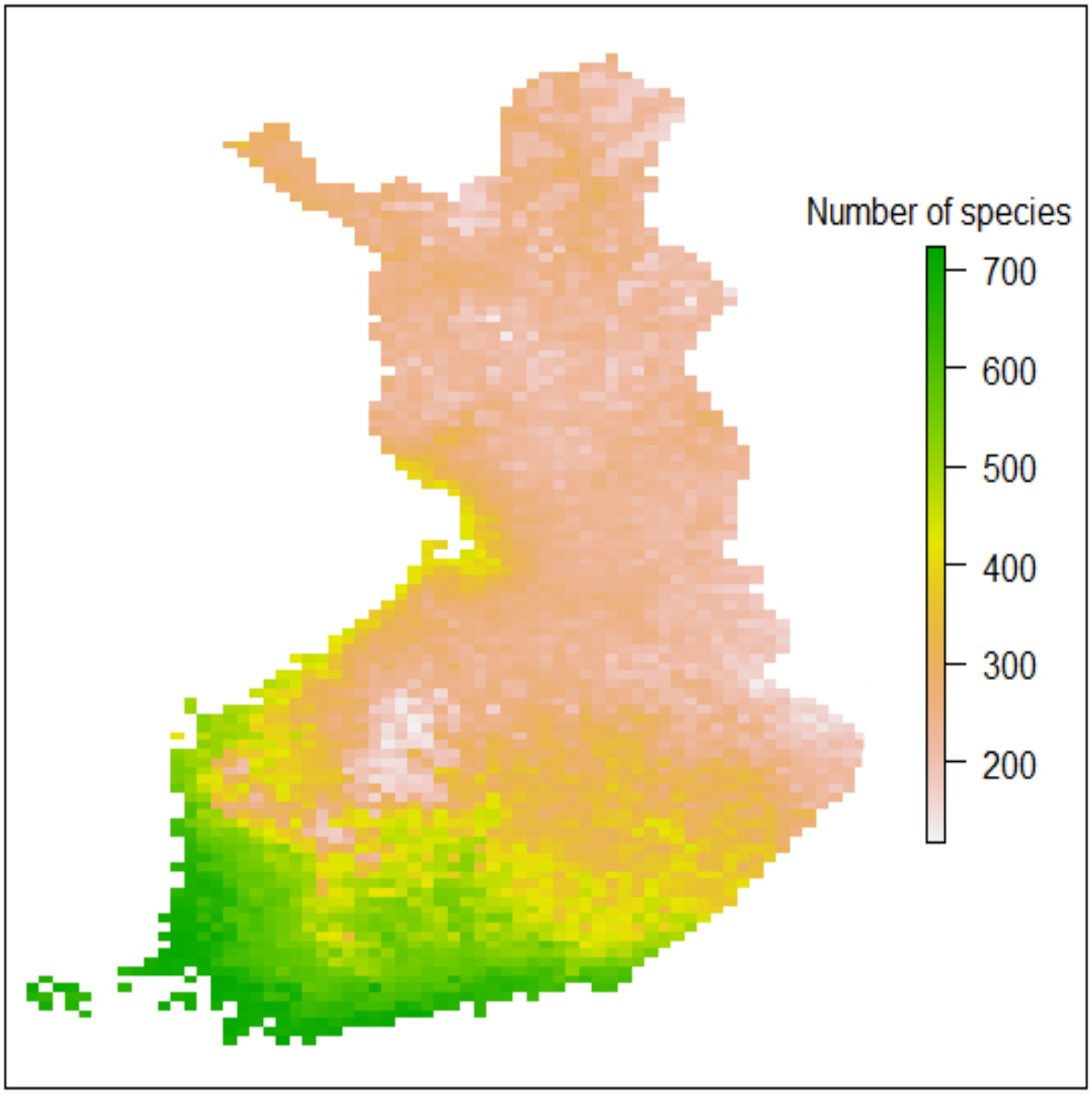

FIGURE 4. Taxonomic diversity or species richness of vascular plants in Finland. The taxonomic diversity is highest in southern Finland and decreases northwards.

Taxonomic diversity (species richness) was highest in southern Finland and lower in the central parts and northern Finland (Fig. 4). Especially along the coast in the southern and south-western archipelagos, taxonomic diversity was high with an estimation of over 700 species of vascular plants for these areas. In northern and eastern Finland, the species richness was around 200-350 species per cell.

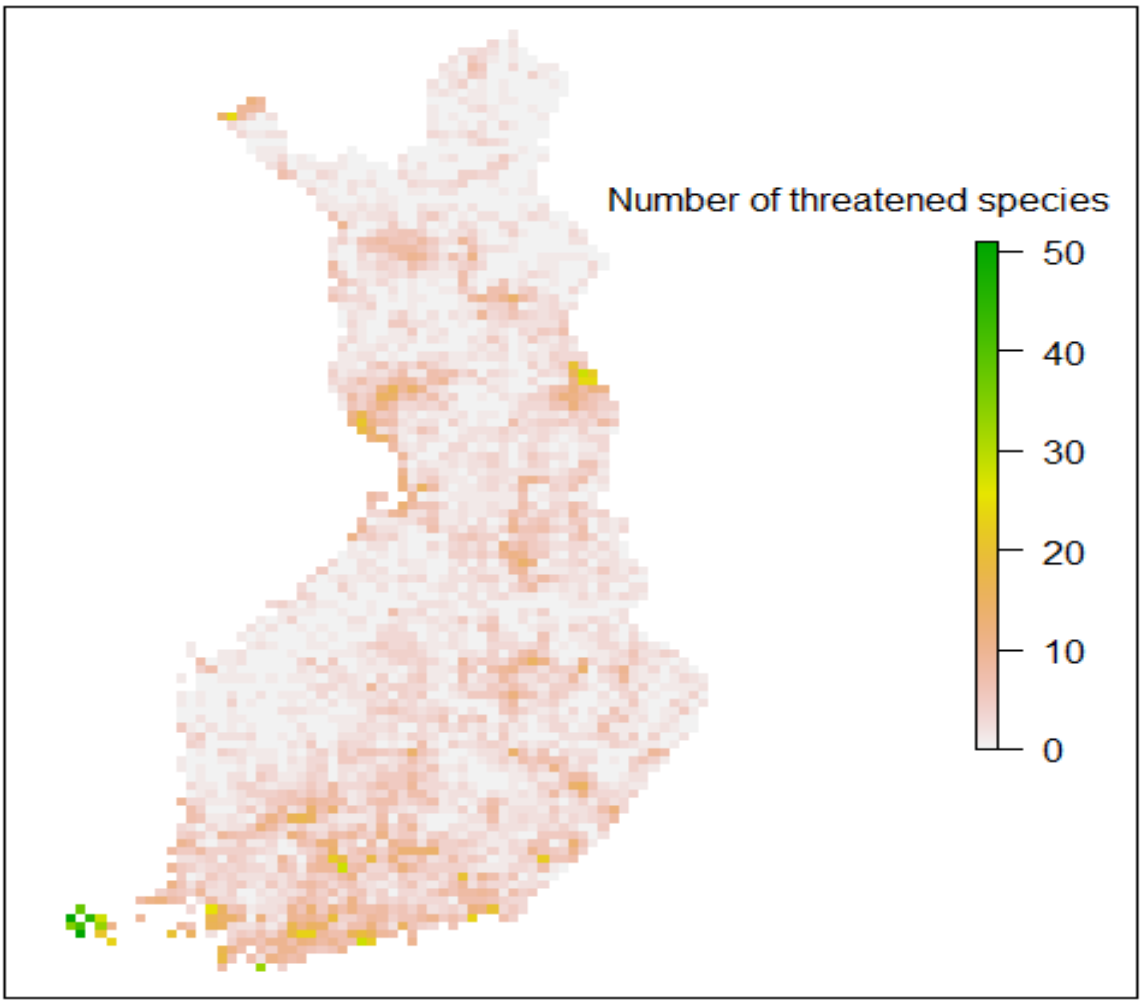

FIGURE 5: Number of threatened vascular plant species in Finland per cell.

The Åland islands have the highest concentration of threatened vascular plants (Fig. 5). Other areas with an abundance of threatened species are the southern coast in general, Kuusamo, the northern parts of Gulf of Bothnia and Kilpisjärvi in northern Lapland (Fig. 5). In addition to these areas, there are other smaller areas with high concentrations of threatened species. Areas with very few threatened vascular plants are Ostrobothnia and some parts of Lapland. On the whole, the distribution of threatened species across Finland does not follow any clear patterns.

3.2 Functional diversity

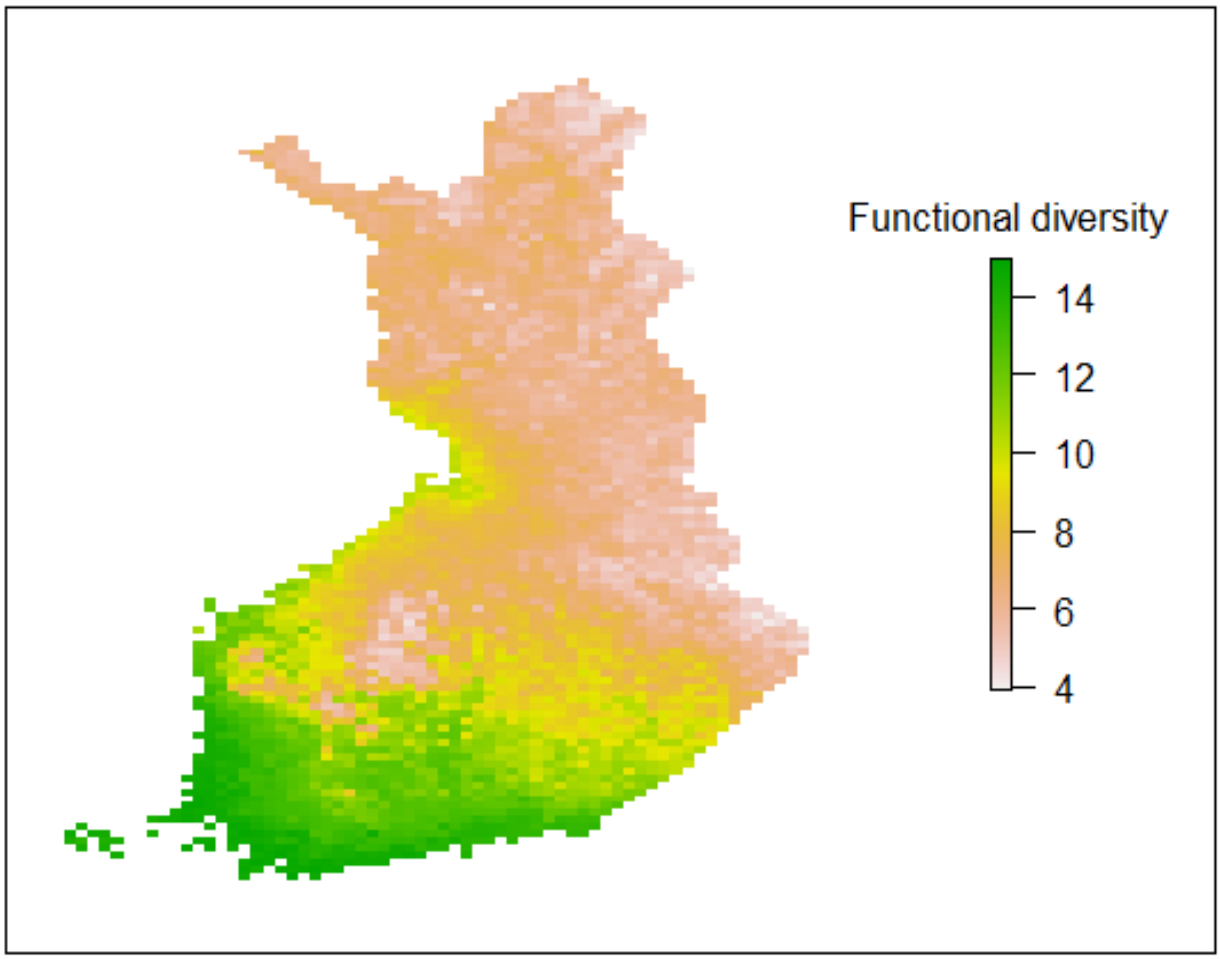

FIGURE 6. Map of the (observed) functional diversity of vascular plants across Finland.

Functional diversity was highest in southern Finland and along the coast (values between 9-14 at most cells, regard that FD is unitless) and declining towards the eastern and northern parts of the country (values between 5-9 at most cells). In northern Lapland, there was a slight increase in the functional diversity when compared to the rest of northern Finland (Fig. 6).

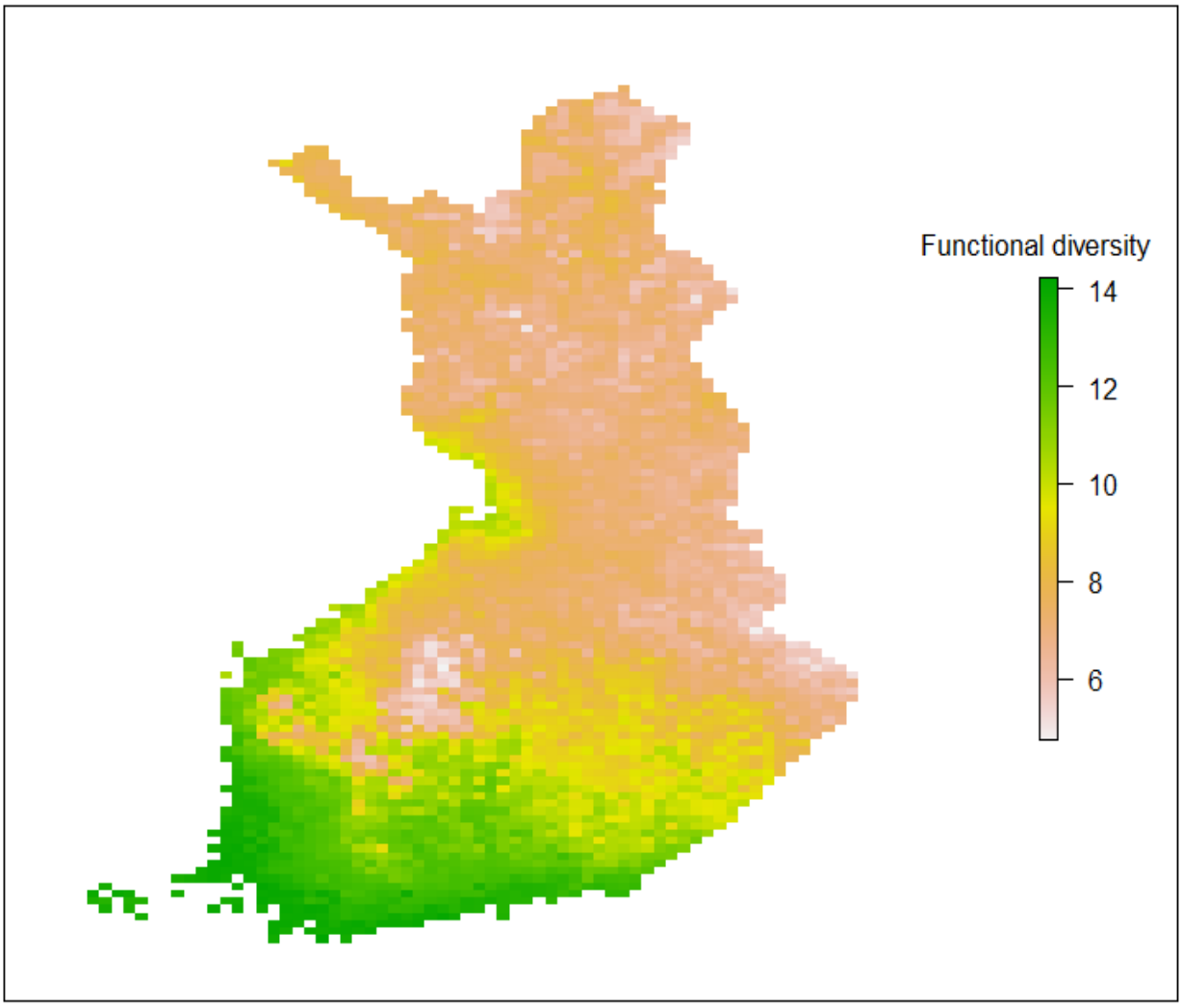

FIGURE 7. Map of expected functional diversity (based on the null model).

The expected functional diversity, based on a null model that kept the species of the sites the same but the functional values were randomized (Fig. 7), resulted in a pattern that resembles the observed functional diversity (Fig. 6). However, the values are slightly lower in southern Finland and higher in northern Finland (Fig. 7) than for the observed functional diversity (Fig. 6).

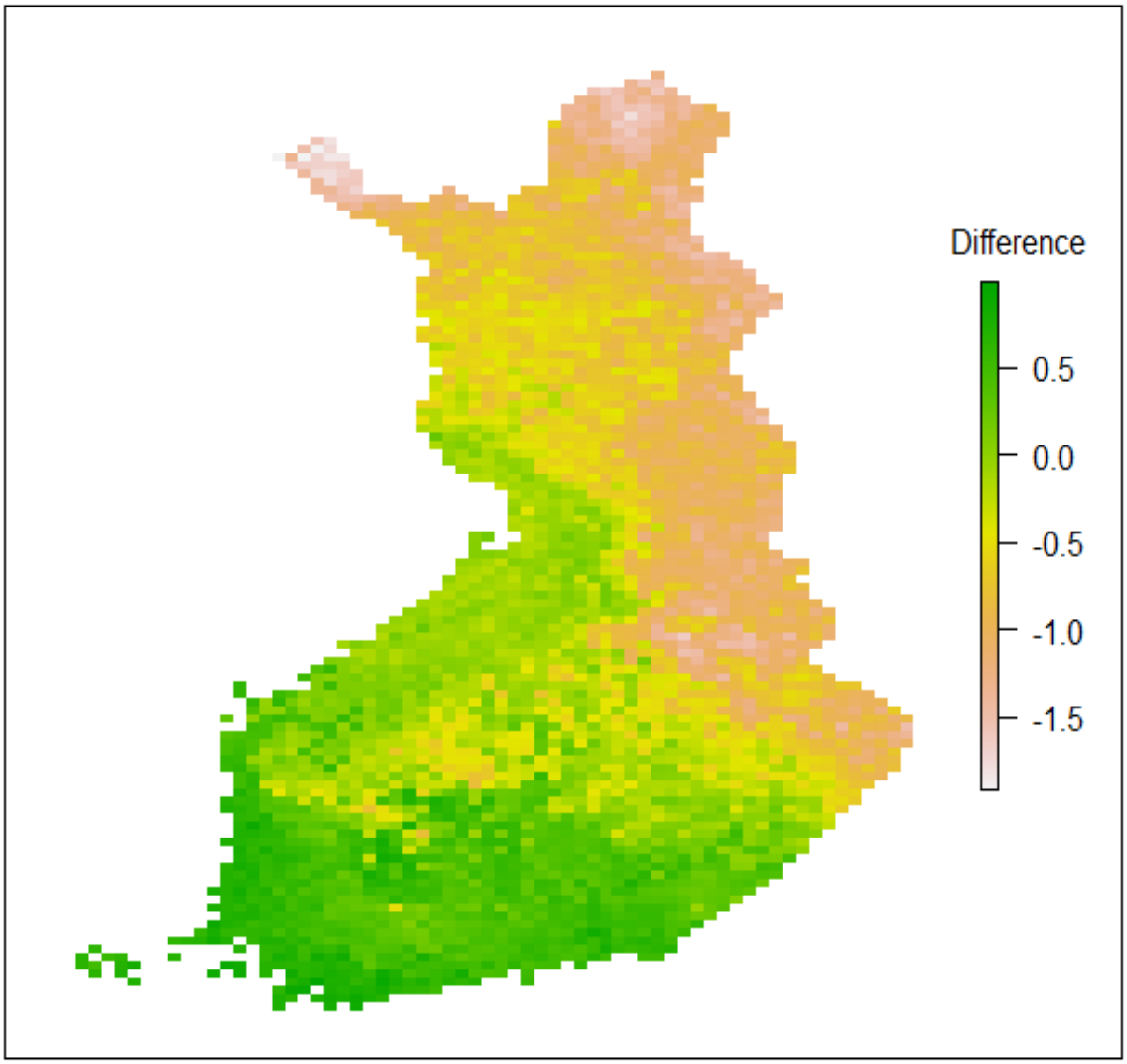

FIGURE 8: Map of difference between the observed and expected functional diversity.

The difference between the expected functional diversity (Fig. 7) and the observed functional diversity (Fig. 6) is illustrated in Fig. 8. The functional diversity was higher in southern Finland and lower in northern Finland than could be expected by chance (Fig. 8).

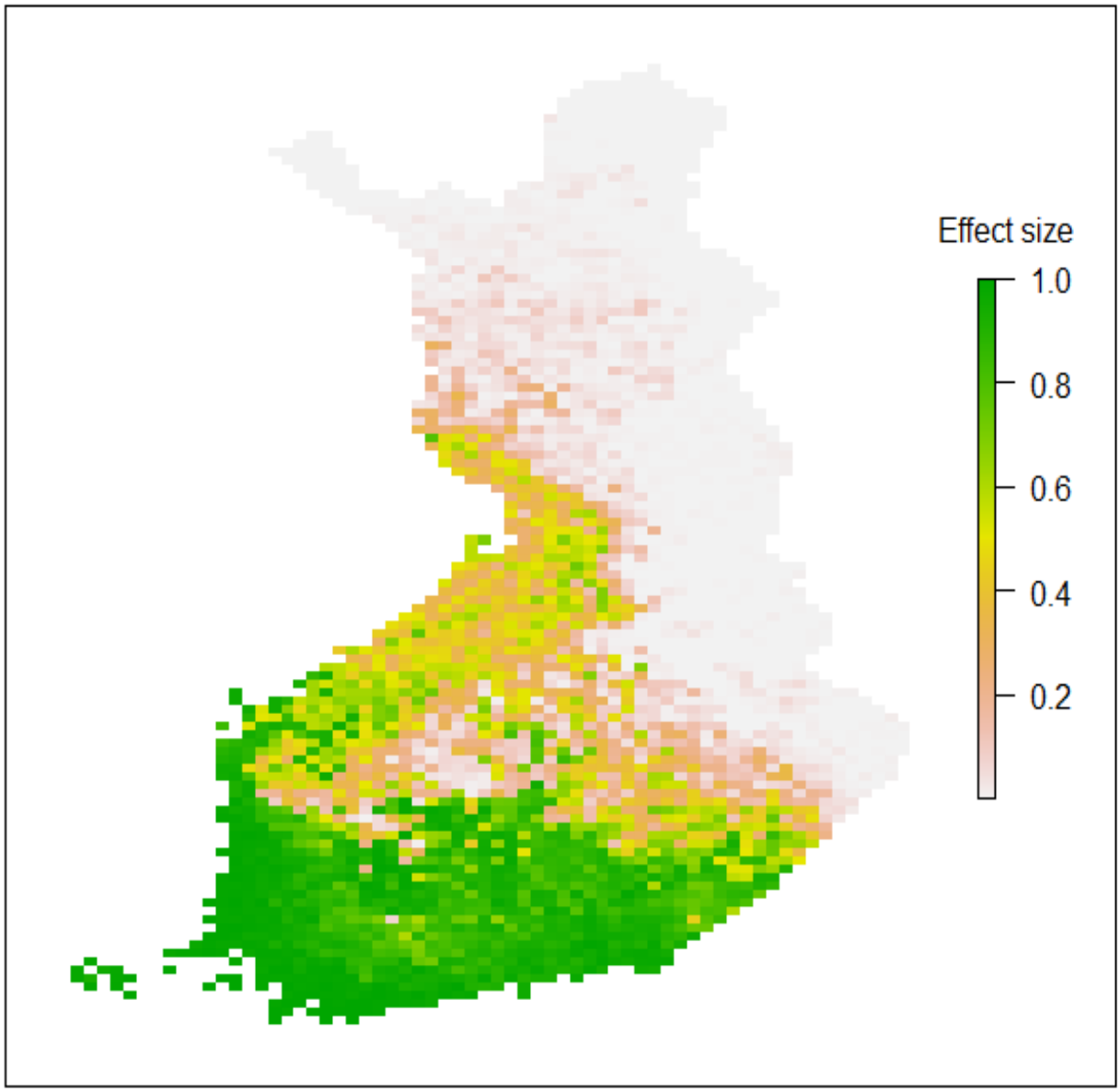

FIGURE 9. Map of the effect size showing the statistical significance for the difference between the observed and expected functional diversity. Light grey cells have a significantly low effect size ($p < 0.025$) and dark green cells have a a significantly high effect size ($p > 0.975$).

The effect size was very significant both for northern Finland with lower functional diversity ($p < 0.025$) and southern Finland with higher functional diversity ($p > 0.975$) than could be expected by chance (Fig 9).

3.3 Red List Index

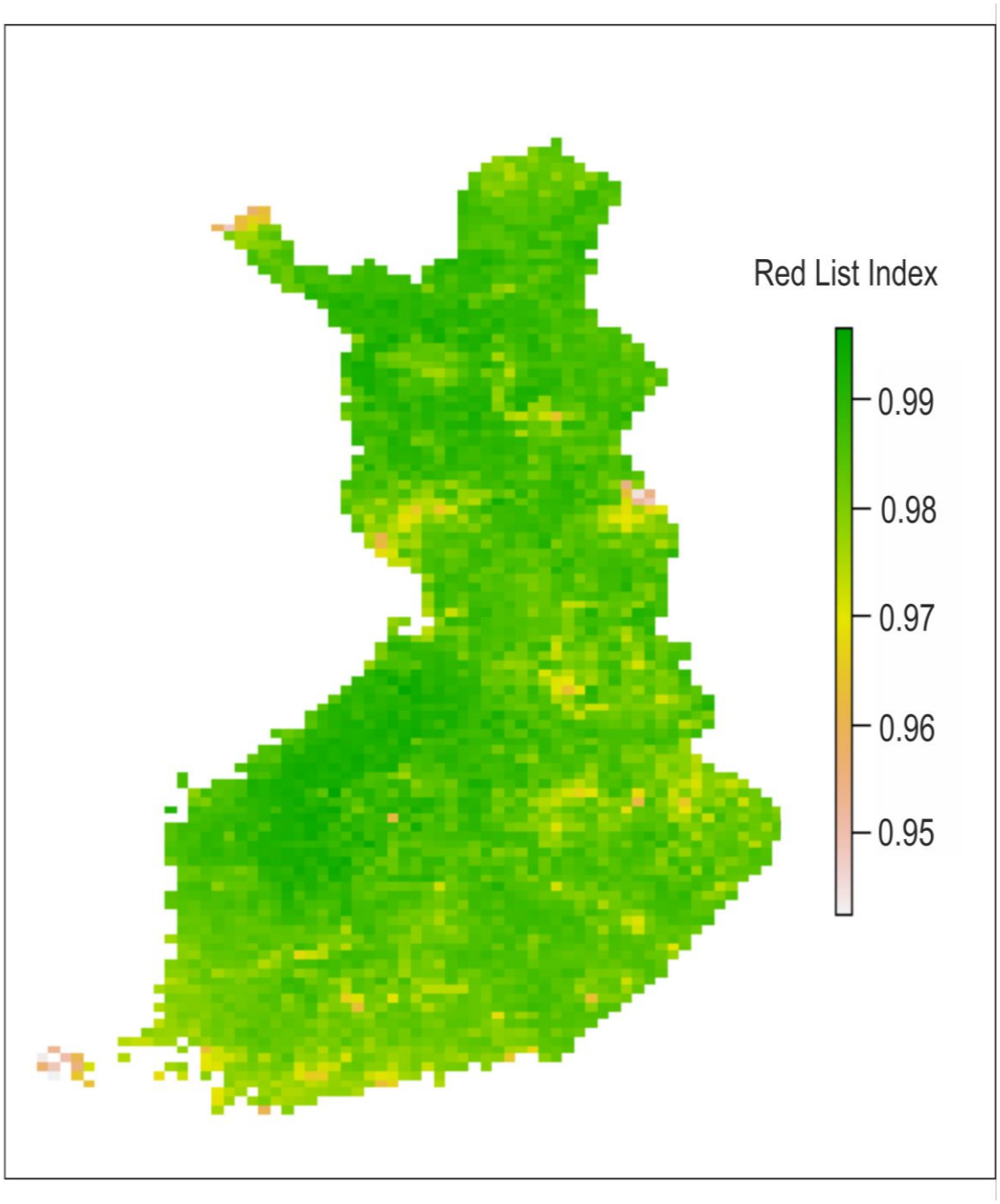

FIGURE 10. Red List Index values across Finland.

The Red List Index was lowest in regions close to the Åland Islands, Kilpisjärvi in the northern Lapland, Kuusamo-Oulanka region in northeast and the northern parts of the Gulf of Bothnia and Kemijoki river (Fig. 10). Besides these sites the results suggest a slightly lower Red List Index also for some of the eastern parts of Finland and the southern coastline. All cells had Red

List Index values between 0.942 and 0.997, values between 0.98 and 0.99 being the most common (Fig. 10).

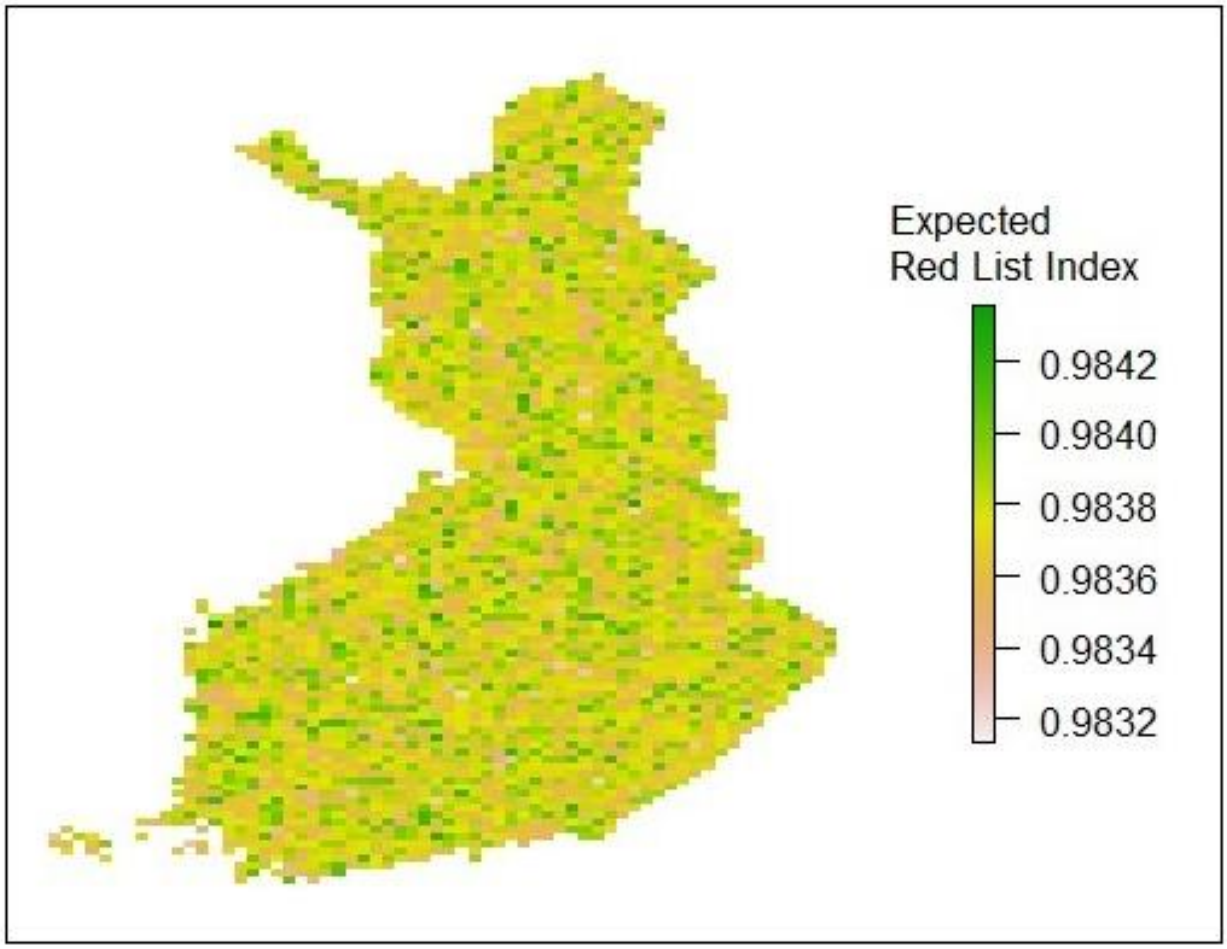

FIGURE 11. Map of expected Red List Index (based on the null model).

The expected Red List Index, based on the null model, illustrates how the distribution of the Red List Index would look like if species richness was the same but the species composition was randomized (along with the species´ threat scores). The null model results in a very even distribution of the Red List Index across Finland, with all values close to 0.9838 (Fig. 11).

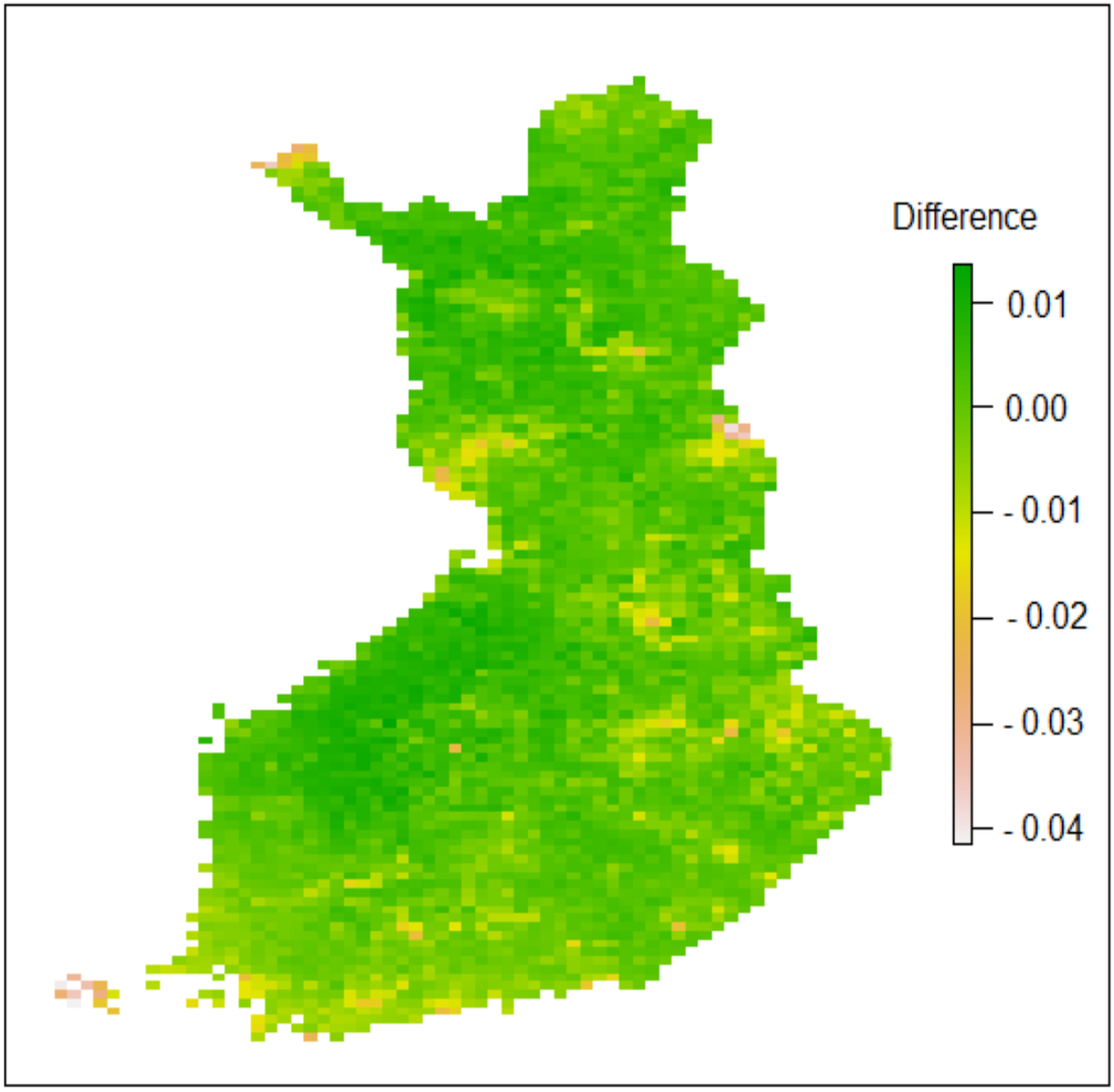

FIGURE 12. Map of difference between observed and expected Red List Index.

The difference between the observed Red List Index (Fig. 10) and the expected Red List Index (Fig. 11) is illustrated in Fig. 12. Cells with yellow, red or white color have lower Red List Index values than could be expected by chance and cells with dak green color have higher Red List Index values than could be expected by chance alone.

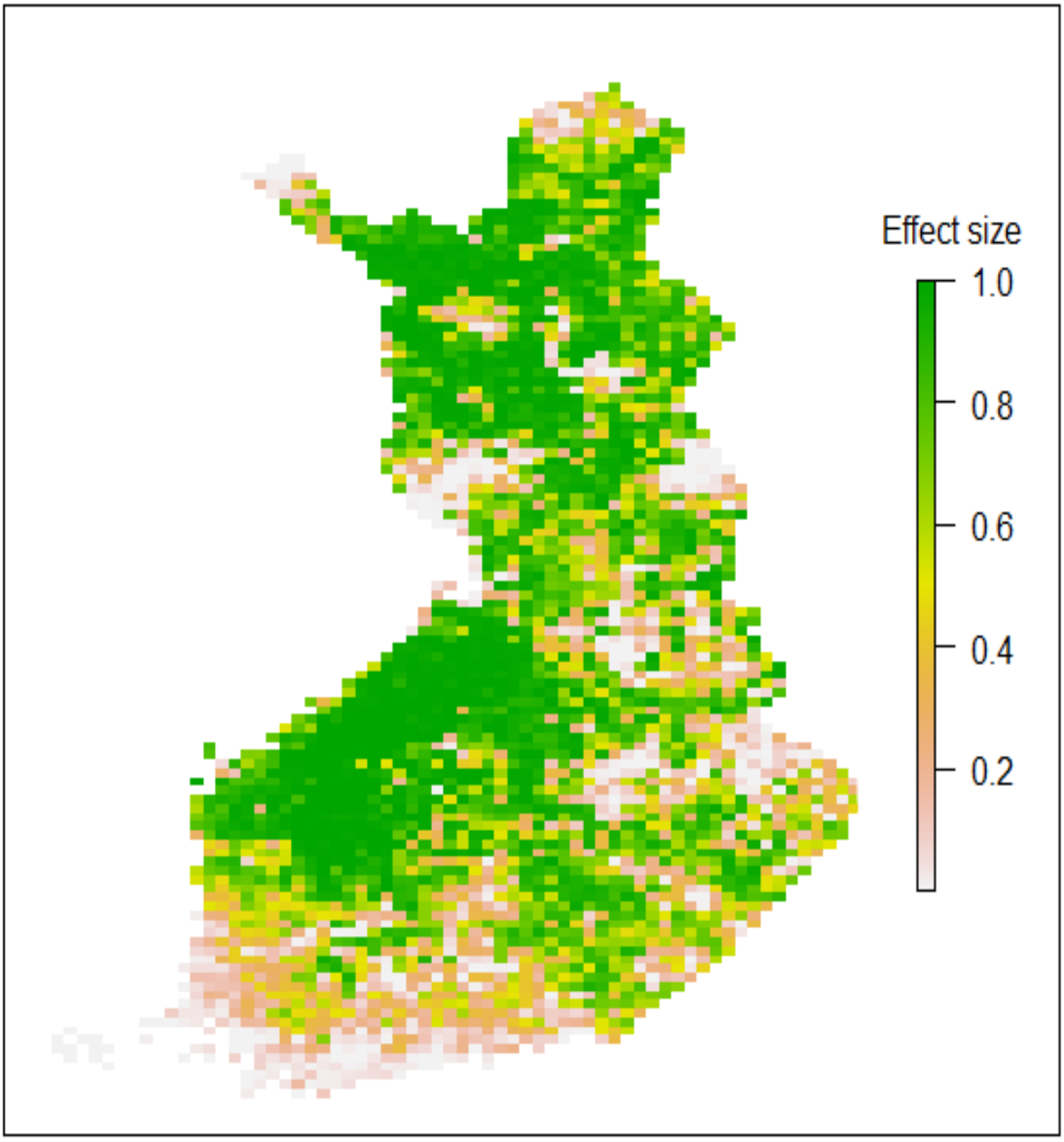

FIGURE 13. Statistical significance for the difference between the observed and expected Red List Index values. Light grey cells have a low effect size ($p < 0.025$) and dark green cells have aa high effect size ($p > 0.975$).

The effect size was calculated for the difference between observed and expected Red List Index values (Fig. 13). The effect size was very significant ($p < 0.001$) for southern Finland, parts of eastern Finland and the areas discussed above (Åland, Kilpisjärvi, Oulanka-Kuusamo, Gulf of Bothnia-Kemijoki river). The effect size was also very significant ($p = 1$) for Ostrobothnia where the Red List Index values were much higher than could be expected by chance (Fig. 13).

3.4 Correlations to environmental variables

Taxonomic diversity was strongly negatively correlated to altitude and temperature annual range. On the other hand, it was strongly positively correlated to annual mean temperature, maximum temperature of warmest month, minium temperature of coldest month, mean temperature of driest quarter, mean temperature of warmest quarter and mean temperature of coldest quarter. For land cover, strong positive correlations were observed for urban areas, urban green areas and arable land and pastures. For the rest of the tested environmental variables the correlations were all either moderate (0.40-0.59) weak (0.20-0.39) or very weak (0.00-0.19). However, even these correlations were all statistically very significant, with one exception; fresh water bodies (Table 8).

Functional diversity was very strongly negatively correlated to altitude and strongly negatively correlated to temperature seasonality, temperature annual range and land cover "inland marshes and peatbogs". A very strong positive correlation was found for annual mean temperature, minimum temperature of coldest month and mean temperature of driest quarter. A Strong positive correlations between functional diversity was recorded for BIO 9-11, BIO 19, urban areas, urban green areas and arable land and pastures. For the rest of the tested environmental variables the correlations were all either moderate (0.40-0.59) weak (0.20-0.39) or very weak (0.00-0.19). All correlations, except from land cover fresh water bodies, were statistically very significant (Table 8).

For threatened species only, there were no very strong or strong correlations. Urban green areas had a moderate positive correlation. All other correlation coefficients were below 0.40 indicating only weak or very weak correlations. However, the observed correlations were all statistically very significant ($P > 0.001$) except from land cover natural grasslands, moors, heathland and transitional woodland (Table 8).

For the Red List Index there were no very strong or strong correlations. All correlation coefficients where below 0.5 indicating only moderate, weak or very weak correlations. However, the observed correlations were all statistically very significant ($P > 0.001$) except from the LC 10 (land cover: beaches, dunes, rock and sparsely vegetated areas). Weak correlations (Spearman 0.20-0.39) were found for instance, for altitude and almost all climatic variables (BIO) and urban areas, urban green areas, agro-forestry areas and coniferous forests.

Very weak (Spearman 0.00-0.19) correlations were observed for, for instance BIO3, arable land and pastures and broad-leaved forests. The only moderate correlation for the Red List Index was found for Mean Diurnal Range (BIO2) (Table 8).

TABLE 8. Spearman Rank Correlations between the spatial distribution of taxonomic diversity, functional diversity, threatened vascular plants and Red List Index and the bioclimatic and environmental variables used in the species distribution modelling. The abbreviation LC in this table stands for Land Cover. Statistical signifcance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Layer Code	Environmental Variable	Taxonomic diversity	Functional diversity	Threatened species only	Red List Index
ALT	Altitude	-0.747***	-0.810***	-0.251***	0.245***
BIO1	Annual Mean Temperature	0.784***	0.836***	0.307***	-0.310***
BIO2	Mean Diurnal Range	-0.462***	-0.433***	-0.260***	0.461***
BIO3	Isothermality (BIO2/BIO7) (* 100)	0.161***	0.179***	-0.090***	0.185***
BIO4	Temperature Seasonality (standard deviation *100)	-0.655***	-0.653***	-0.147***	0.191***
BIO5	Max Temperature of Warmest Month	0.719***	0.771***	0.297***	-0.283***
BIO6	Min Temperature of Coldest Month	0.769***	0.806***	0.278***	-0.311***
BIO7	Temperature Annual Range (BIO5-BIO6)	-0.700***	-0.690***	-0.203***	0.298***
BIO8	Mean Temperature of Wettest Quarter	0.468***	0.484***	0.253***	-0.310***
BIO9	Mean Temperature of Driest Quarter	0.788***	0.835***	0.300***	-0.287***
BIO10	Mean Temperature of Warmest Quarter	0.722***	0.770***	0.330***	-0.347***
BIO11	Mean Temperature of Coldest Quarter	0.773***	0.815***	0.264***	-0.284***
BIO12	Annual Precipitation	0.481***	0.497***	0.287***	-0.374***
BIO13	Precipitation of Wettest Month	0.324***	0.323***	0.150***	-0.239***
BIO14	Precipitation of Driest Month	0.385***	0.394***	0.288***	-0.377***
BIO15	Precipitation Seasonality (Coefficient of Variation)	-0.401***	-0.429***	-0.248***	0.302***
BIO16	Precipitation of Wettest Quarter	0.355***	0.364***	0.216***	-0.296***
BIO17	Precipitation of Driest Quarter	0.448***	0.458***	0.288***	-0.382***
BIO18	Precipitation of Warmest Quarter	-0.053*	-0.066***	0.107***	-0.200***
BIO19	Precipitation of Coldest Quarter	0.587***	0.602***	0.319***	-0.397***

LC 1	Urban areas	0.674***	0.716***	0.366***	-0.276***
LC 2	Urban green areas	0.676***	0.708***	0.421***	-0.343***
LC 3	Arable land and pastures	0.683***	0.744***	0.247***	-0.167***
LC 4	Agro-forestry areas	0.412***	0.447***	0.349***	-0.291***
LC 5	Broad-leaved forests	0.431***	0.420***	0.157***	-0.144***
LC 6	Coniferous forests	-0.381***	-0.340***	-0.196***	0.224***
LC 7	Mixed forests	0.238***	0.284***	0.202***	-0.084***
LC 8	Natural grasslands, moors, heathland	-0.229***	-0.341***	-0.206	0.092***
LC 9	Transitional woodland / shrub	-0.207***	-0.141***	-0.016	0.101***
LC 10	Beaches, dunes, bare rock, sparsely vegetated areas	0.146***	0.110***	-0.012***	-0.020
LC 11	Inland marshes, peatbogs	-0.596***	-0.607***	-0.299***	0.312***
LC 12	Salt marshes	0.331***	0.328***	0.228***	-0.246***
LC 13	Fresh water bodies	0.029	0.019	0.124***	-0.144***

4. DISCUSSION

4.1 Taxonomic diversity patterns

Taxonomic diversity showed a strong latitudinal gradient with decreasing biodiversity towards the north. The observed patterns roughly correspond with the vegetation zones in Finland. The south-western archipelago and a small section of the coast eastwards along the Gulf of Finland had highest taxonomic diversity with over 700 species per cell and belongs to the hemiboreal zone (National Board of Survey & Geographical Society of Finland 1988). Further away from the coast the species diversity is at 600–400 species per cell and this zone corresponds to the southern boreal zone. North of this the species diversity continues to decrease. There is no sharp contrast in taxonomic diversity between the middle boreal and northern boreal vegetation zones. In general, the species richness is double in southern Finland compared to Lapland.

According to Boucher-Lalonde et al. 2013 the environment acts as top–down mechanism that affects how many species can occur on a given site. Currie (1991) found that climate is the one stronger limiting factors for species richness on larger scales. My results support this as I found a strong positive correlation between taxonomic diversity and mean temperature. The results of this thesis are thus consistent with theories of how the latitudinal gradient affects taxonomic diversity. What further explains the high species richness in the south is the high amount of archeophytes in southern Finland that increases the diversity (Kalpio & Bergman 1999).

In some sites in northern and eastern Finland the diversity is higher than in surrounding regions. This is probably due to sites with a richer flora as a result of a calcareous bedrock, sites with a broad variety of habitats or varying topography and microclimate. As my results are based on species´ distribution models and these results are in accordance with Lampinen & Lahti (2015) (Fig. 2) it can be assumed that the SDM: s predicted the species´ distributions successfully.

Functional diversity followed very closely the same patterns as taxonomic diversity (Table 8). Thus, it seems that it is the same environmental variables that affect both taxonomic and functional diversity for vascular plants in Finland.

4.2 Functional diversity patterns are driven by environmental filtering and competitive exclusion

To test whether or not the functional diversity was higher or lower than expected by chance it was compared against a null model (Fig. 7). The expected functional diversity (Fig. 7) looks very similar to the observed functional diversity (Fig. 6), however, there are differences. These differences are visualised in Fig. 8. Generally, the values for the expected functional diversity was lower in southern Finland and higher in northern Finland than for observed functional diversity. Therefore, functional diversity was higher than expected by chance in southern Finland and lower than expected by chance in central and northern Finland. This could partly be explained by the high taxonomic diversity in southern Finland. On species rich sites, there is a theoretical possibility for higher functional diversity simply because more species might have more trait combinations than a species poor site.

The lower functional diversity than expected by chance probably reflects a high environmental stress that limits species´ distributions and is commonly reffered to as environmental filtering. The concept of environmental filtering means that there are abiotic factors like temperature, precipitation and seasonality that make it impossible for all species to survive at a certain location. The environmental conditions "filter" the species assemblage so that only species with a certain set of functional traits can establish and persist in the habitat while it excludes species that do not have these traits, thus reducing the viable strategies for plants in these habitats (Bazzaz 1991; Pottier et al. 2012; Swenson et al. 2012; Hawkins et al. 2013; Passy et al. 2017). Thus, the environment can be viewed as a selective force, excluding species from locations that do not possess the right set of traits (Thakur & Wright 2017). Earlier studies have shown that functional diversity decreases with latitude (e.g Swenson & Enquist 2007; Hawkins et al. 2013; Lamanna et al. 2014) and with altitude because of environmental filtering (e.g Pottier et al. 2012). My results further strengthen these earlier findings. Northern and eastern Finland have a more continental climate with colder and harsher winters than the southern and western parts of the country (National Board of Survey & Geographical Society of Finland 1988). Especially in the fells in northern Lapland, the functional diversity is low. For instance, chaemophytes and hemicyptophytes are the dominating plant life forms in the Finnish fells (Kalliola 1973). In habitats in southern Finland, however, the diversity of life forms is much wider and thus, the functional diversity is higher there. In addition, many archaeophyte species have not either been able to establish or are not able to persist in northern and eastern Finland because of both

environmental filtering and historic reasons the number of archaeophytes are higher in southern Finland.

Besides climate filtering, habitat filtering might also play a role in trait composition of assemblages. A good example of a habitat with strong environmental filtering is mires. Mires had a strong negative correlation with functional diversity. Mires act as a filter as it is a very demanding habitat. Mires typically have low pH values, there are often lack of oxygen in the rhizosphere and further, the mire as an environment is usually wet but can occasionally dry up. Open mires also offer little protection from cold and wind during winter (Tahvanainen 2005). Those few species that can survive on mires have the right functional traits as a result of adaptation to the habitat. As they all have adapted to the same environmental conditions, they share many of the traits, which results in a relatively low functional diversity for mires.

Precipitation patterns affected functional diversity far less than temperature. For annual temperature, there was a modest positive correlation. This corresponds well to the more marine climate along the coast where both taxonomic and functional diversity were high.

Functional diversity was higher than expected by chance in Southern Finland and along the coastal areas. According to the principle of competitive exclusion two species cannot coexist at the same location if they have exactly the same niche (Gause 1934). In environments with plentiful resources interspecific competition usually leads to a situation where closely related species do coexist less often than expected by chance (Odriozola et al. 2017). The high levels of interspecific competition affect functional diversity in two ways. First, functionally similar species will be excluded by competition from sites with high species richness. Instead of having many species with similar traits, species rich sites therefore have a wider spectrum of functional traits to avoid direct competition from other species. Secondly, competition leads to a high taxonomic and functional diversity as a result of niche adaptation so that multiple similar species can coexist as they all have slightly different niches and therefore, also slightly different functional traits (e.g. Ricklefs & O'Rourke 1975; Odriozola et al. 2017). As a result of competition and niche adaptation all species in species-rich habitats have different functional traits which results in a high functional diversity and affects the assemblage of the plant community (Cavender-Bares et al. 2009; Odriozola et al. 2017). My results indicated that urban areas, urban green areas, arable lands and pastures and broad-leaved forests are examples of this phenomenon. On a larger scale, the whole southern Finland had a higher functional

diversity than could be expected by chance because of suitable environmental conditions and strong competition among the species.

Slightly surprising, agro-forestry areas had a weak positive correlation to functional diversity whereas coniferous forests had a weak negative correlation. A possible explanation to this might be that in agro-forestry areas the forests are usually highly fragmented and consist of patches of clear cut areas, younger stands, mature stands and older forests and small roads that cross these areas. Studies have shown that gaps caused by disturbances can increase diversity (e.g. Brown & Jennings 1998; Brokaw & Busing 2000; Schnitzer & Carson 2001). In landscapes with gaps or fragmented forests the increased edge effect could explain higher functional diversity values. Especially on clear cut areas the species´ competition is high as many plant species try to colonize and persist in the initial phase of the succession. This could increase the functional diversity. However, my results should not be interpreted as managed forests should be preferred on the cost of forests in natural condition to maintain a high functional diversity. The higher functional diversity values in managed forests is likely due to higher numbers of archaeophytes and species early in the succession stage, which benefit from the forests being managed and fragmented. They represent completely different plant communities than those found in old-growth forests. In managed and fragmentized forest landscapes, the amount of neophytes is likely to be higher than in forests in natural condition. As neophytes were excluded from this thesis their presence or absence did not affect my results.

Recently, much ink has been spilled on both critizing and defending the theory of environmental filtering (see e.g. Kraft et al. 2015; Cadotte & Tucker 2017; Thakur & Wright 2017). For instance, Kraft et al. (2015) suggested that the current use of the term environmental filtering usually overstates the role of abiotic factors on the cost of biotic facors like competition. It is clear that competition and other biotic facors like dispersal affect the distribution of functional diversity not only in southern Finland (as the theories of environmental filtering and competitive exclusion would predict) but also in northern Finland even if competition arguably is not as strong here as in the species rich southern Finland. Several studies have shown that on large scales abiotic factors are the most important variables affecting community structure and that competition is important only on local scales (Pearson & Dawson 2003; Soberón and Nakamura 2009; Araújo & Rozenfeld 2014). Therefore, I think that the theories of environmental filtering and competitive exclusion applies to the distribution of functional diversity for Finnish vascular plants. My conclusions are supported by several studies that have

found that spatial patterns of functional diversity are driven by environmental filtering and competitive exclusion (e.g. Cornwell et al. 2006; Zhang et al. 2017). In future studies however, it could be useful to incorporate biotic variables in species´ distribution models to avoid neglecting the role of competition.

4.3 Red List Index patterns

For the first time, the distribution of the Red List Index was mapped across a whole country. All sites had Red List Index values between 0.942 and 0.997. It is logic that all Red List Index values are close to 1 – for the index to be significantly lower than 1 it would demand a high portion of near threatened, threatened and extinct species and comparatively few LC species. However, most Finnish vascular plant species are classified as LC (Rassi et al. 2010) explaining the relatively high observed values.

The Red List Index correlated only weakly or very weakly with almost all environmental variables. A similar pattern was observed when analyzing only threatened species. Thus, it seems that the Red List Index is not primarily driven strongly by any of the variables I checked for. Instead, the Red List Index is probably affected by all of them a little bit – this is supported by the fact that the p-values were very significant although the correlations were not strong. In addition, it is possible that the distribution of Red List Index values across a country is also affected by soil properties and changes in land use during the last decades and in the end, not that much of the current land cover.

The Red List Index was found to be weakly negatively correlated to temperature. This is most likely due to the high concentration of threatened plants in southern Finland and the latitudinal gradient discussed earlier that applied to taxonomic and functional diversity. The Red List Index had a similar negative correlation to precipitation, especially precipitation during the coldest month of the year. One possible explanation is that areas with high amounts of precipitation during the coldest month of the year also have a thick snow cover. Snow cover is an important ecological variable that could favour alpine and arctic species. Specialized species like these are more likely to be threatened, which could explain the observed correlation between lower Red List Index values and higher precipitation.

The observed correlations between the Red List Index and the environmental variables discussed above where also reflected in the relationship between the environmental variables and threatened species – with the only difference being that the correlation was usually the opposite than for the Red List Index. For instance, mean temperature had a weak positive relationship with threatened species but a weak negative correlation to the Red List Index. This is logic because generally, the warmer the mean temperature a site has, the more threatened species it hosts ("more threatened species in southern Finland than northern Finland") which at the same time decreases the potential Red List Index value for that site. This creates the observed pattern with opposite correlations for the Red List Index and the threatened species. This pattern is evident in almost all variables when comparing the threatened species and Red List Index.

The Red List Index was negatively correlated to urban areas, urban green areas and arable lands and pastures. This was somewhat surprising as I had assumed that the threatened species would already have disappeared from heavily human influenced areas. On the other hand, many archaeophytes are common in urban areas and sites with long cultural history (Kalpio & Bergman 1999; Hæggström 2000) and along roads and railways many declining meadow species have found a refuge (Ryttäri et al. 2012) which might explain the lower Red List Index values in urban and urban green areas. My results further underline the importance of rural habitats for threatened vascular plants in Finland. In addition, most urban areas are found in southern Finland where the biodiversity among vascular plants nonetheless is highest. This might also partly explain why the Red List Index is slightly lower in urban areas.

To my surprise mires showed a weak positive correlation to the Red List Index as I had expected an opposite trend. According to Kaakinen et al. (2008) 57% of all mire habitats in Finland are threatened. There is no country in the world that has drained more mires than Finland and in southern Finland an estimated 75% of the mires have been drained (Aapala 2001a; Lindholm & Heikkilä 2006). Many mire species disappear from drained mires and simultaneously the drained mire is slowly colonized by primarily forest species (Aapala 2001a; Uusitalo et al. 2006). With such an extensive loss of habitat it is possible that the extinction debt for mires in southern Finland has already partly been paid – meaning that local extincions have already occurred. Therefore, past changes and loss of biodiversity in the mire landscape might explain the positive correlation between the Red List Index and mires. As the land cover data I used did not separate mires in natural condition from drained mires it can be assumed that it is the high

percentage of drained mires and their "forestlike flora" that is the key to the observed positive correlation as locations with drained mires are likely to not have any threatened plants at all. The positive correlation should not be interpreted as the mires and mire flora would have been successfully protected in Finland – rather, it is a reminder of the impoverished diversity of vascular plants after decades of extensive destruction of mires.

4.3.1 Sites with low Red List Index values

The Red List Index values for Finnish vascular plants were not clearly associated with latitude when compared to taxonomic and functional diversity. On the contrary, the results showed so called "hot spots" where the Red List Index is lowest i.e. where there is a high concentration of threatened species. These hot spots are the southwestern archipelago (especially the Åland islands), the Kilpisjärvi region in northwestern Lapland, the Kuusamo region in eastern Finland and the area around the Gulf of Bothnia and Kemijoki river. These findings were further reaffirmed by the effect size that showed statistically significant lower Red List Index values for these areas but also for the southern coastline, southern Finland in general and small fragmented sites in parts of northern and eastern Finland (Fig. 13 & 14).

These "hot spots" all represent geographical "extremes" in Finland and are thus also floristically special. What many of the sites with low Red List Index values share in common is a calcareous rich bedrock consisting of either limestone or dolomite (Fig. 14). Studies have shown (e.g. Silfverberg et al. 2005; Oldén et al. 2016) that plant species diversity is higher on calcareous rich soils than in acid soils. Calcium rich soils are often poor in phosphates, which makes it difficult or impossible for many plants to persist on such sites (Tyler 1992). Plants that avoid calcareous locations are called calcifuge species and plants that prefer calcareous soils are called calcicoles (Eklund 1948; Grime & Hutchinson 1967). It has been discussed whether calcicole plants thrive on calcareous soils because of the calcium itself, or if the are poor competitors in calcium depleted soils. For instance, for some orchids the latter seems to be the case (Mossberg & Ærenlund Pedersen 2017). Calcium-rich soils have a high pH, which increases the solubility of the nutrients, thus making theme more available for plants (e.g. Gensac 1990; Eskelinen 2008; McCauley et al. 2017). According to Jefferies & Willis (1964), it is therefore possible that the calcicole plants are dependent not only on calcium itself, but also by the increased solubility of other nutrients.

As most of the soils in Finland are acid and calcareous areas are highly restricted many calcicole plant species thrive in these areas and cannot survive elsehere. This is reflected in both the speciality of the plant communities and the observed low Red List Index values on many calcareous sites (Figure 14). Examples on threatened vascular plant species that prefer calcareous soils include *Aconitum lycoctonum* (VU), *Antennaria porsildii* (VU), *Botrychium virginanum* (EN), *Eriophorum brachyantherum* (VU), *Orchis militaris* (EN) and *Viola rupestris* subsp. *relicta* (EN) to name a few (Ryttäri et al. 2012).

Plants that are dependent on calcareous soil can be used as indicators for sites with high biodiversity (Silfverberg et al. 2005). My results add another dimension to this theory as areas with low Red List Index values and calcareous sites seem to correlate (Figure 14). Unfortunately, within the timetable of this thesis it was not possible to calculate the correlation nor the statistical significance between the calcareous areas and the Red List Index results, so it remains for further studies to prove how strong the correlation is.

Further, the sites with low Red List Index values are defined by the fact they represent areas with a broad range of environmental conditions; varying microclimate, varying bedrock and varying topography. These varying conditions support greater number of species than more homogenous areas (Gurevitch et al. 2006). Next, I will present these hot spots areas in short and explain what might lie behind the low Red List Index values.

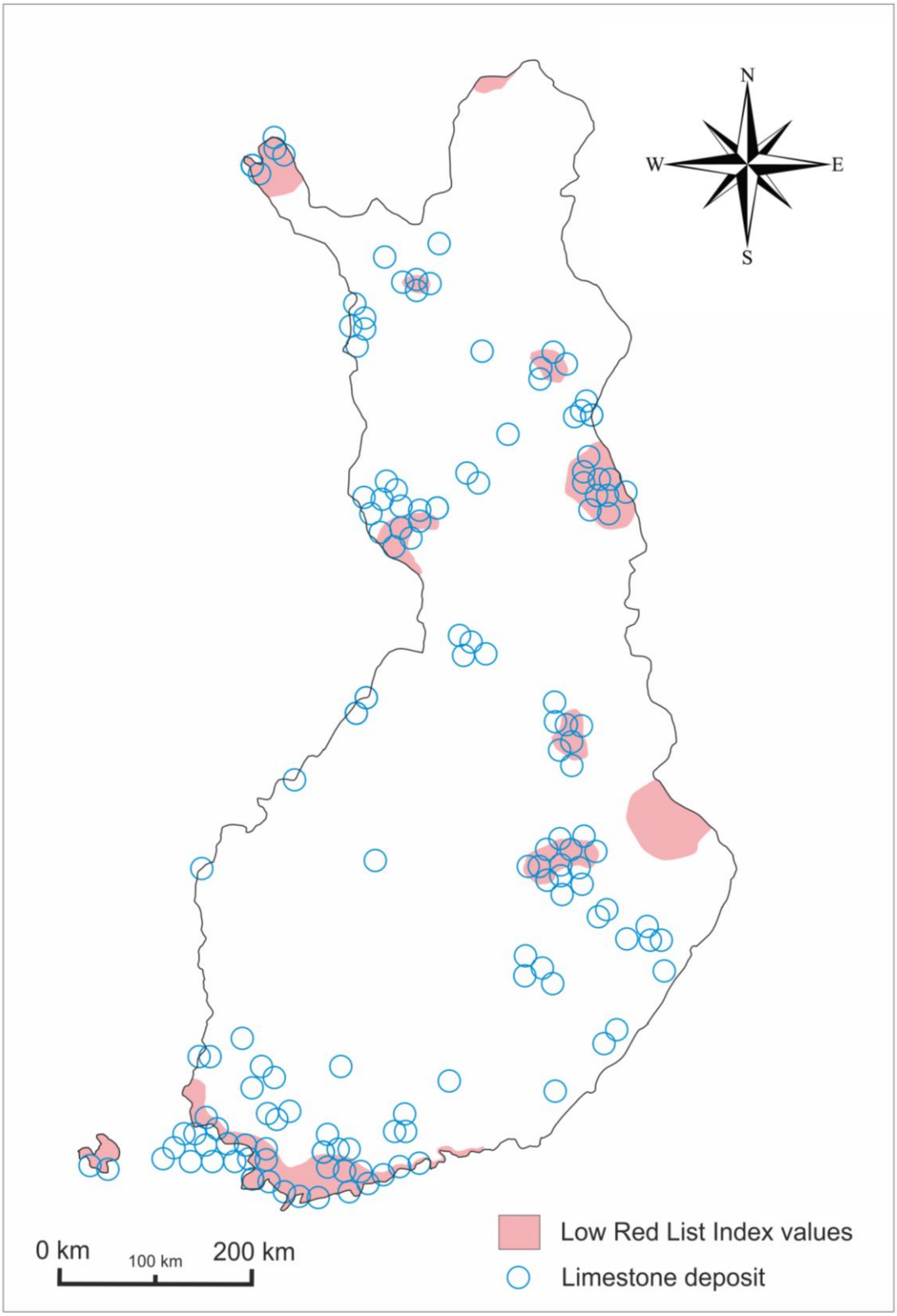

Figure 14. Areas with lower Red List Index values than could be expected by chance (based on Fig. 10 & 13) and limestone deposits in Finland. Data for the limestone deposits was obtained from bedrock maps produced by the Geological Survey of Finland (Geological Survey of Finland 2017). Limestone and dolomite marked areas were incorporated to this map.

Åland belongs to the hemiboreal zone and has a very mild, oceanic climate and belongs to the area that has the highest taxonomic and functional diversity in Finland. According to Hæggström (2000) the exceptionally rich flora on Åland is explained by of the mild and warm oceanic climate, its favorable geographic characters (a varying topography and bedrock) and long history of cultural influence (abundance of rural biotopes). One of the most vulnerable and species rich habtitats in Finland are wooded meadows (Fig. 15) and Åland is one of the few places where they still exist. Grazing is important to maintain the special flora of all rural biotopes and that is true also for wooded meadows.

Figure 15. Wooded meadow with *Fraxinus excelsior* (LC), *Anemona nemorosa* (LC), *Dactylorhiza sambucina* (NT), *Orchis mascula* (NT), *Primula farinosa* (EN), and *P. veris* (LC). Wooded meadows are vulnerable rural biotopes and one of the most species rich habitats in Finland that host several threatened species. It is one of the reasons why the Åland islands have the most threatened species in Finland and thus, also low Red List Index values. Photographed on Nåtö, Åland 20.5.2015, Jon Rikberg.

Many threatened vascular plant species, e.g. *Liparis loeselii* (CR), *Vicia lathyroides* (VU) and *Viola reichenbachiana* (EN), live exclusively on Åland further underlining how exceptional the flora of Åland is (Hæggström & Hæggström 2010; Ryttäri et al. 2012). Therefore, it is not

surprising that according to my results the Red List Index values for Åland are lower than elsewhere in Finland.

The parts of Finnish Lapland that has lowest Red List Index values are Kilpisjärvi and a small area in the northern part of province Inari Lapland (Fig. 14). Kilpisjärvi, lies in the northwestern corner of Finnish Lapland, close to the border to Norway and Sweden, and is the only area in Finland that belongs to the Scandinavian mountain ridge. Kilpisjärvi region is dominated by mountains that reach up to 1300 m above sea level (Virtanen et al. 1997). Kilpisjärvi has a higher species richness than other parts of Finnish Lapland and the area also hosts many threatened vascular plant species. Only in the Malla and Saana region of Kilpisjärvi there are records of 45 red-listed vascular plant species, which explains the low Red List Index values for the area (Kauhanen 2013; Fig. 10). Examples of threatened vascular plants in the Kilpisjärvi region are *Arenaria norvegica* (VU), *Draba lactea* (VU) and *Ranunculus suphureus* (EN) (Ryttäri et al. 2012). According to Kauhanen (2013) the high species richness and abundance of threatened species in Kilpisjärvi is mainly explained by the calcareous bedrock and a high geomorphological diversity (mountains, slopes, protected valleys) that provide a wide variety of habitats. Additionally, Kilpisjärvi is the only region in Finland with mountains reaching above 1000 m, which also explains why so many arctic and alpine species only thrive in this part of Finland (Kauhanen 2013). 67% of the fell habitat types are either near threatened or threatened and the biggest single threat is overgrazing by reindeer (Norokorpi et al. 2008). Kilpisjärvi is arguably one of the areas where climate change will pose an increasing threat to the flora in the following decades. Therefore, it would be good to track how the Red List Index develops for this particular area.

The third "hot-spot" region is Kuusamo area with Oulanka National Park. As in Åland and Kilpisjärvi the high amount of threatened vascular plants can be explained by the calcareous rich bedrock and a high variability in topography and habitats (Simula & Lahti 2005). These conditions make Oulanka a suitable place to live for many demanding species that cannot survive elsewhere. Lyon et al. (2011) found that the biodiversity of threatened species (fungi, lichen, mosses and vascular plants) inside the Oulanka National Park was at highest 41-67 species per km^2. Oulanka is also a place where many species have their extreme edge of their distribution. For instance, *Fragaria vesca* (LC) has its northernmost distribution in Oulanka and many northern species have their southernmost distribution in Oulanka like *Diphasiastrum alpinum* (LC) and *Saxifraga cernua* (LC) (Lyon et al. 2011). Other species like *Calypso bulbosa*

(VU) is rather common in Oulanka but a rarity in the rest of the country. All these factors, contribute to a high amount of threatened species (Fig. 5) and thus also low Red List Index values for this area (Fig. 13 & 16).

The northern corner of Gulf of Bothnia is the fourth hot spot area for threatened species. The shores of the northernmost parts of the Gulf of Bothnia is home to for instance *Hippuris tetraphylla* (EN) and *Primula nutans* subsp. *finmarchica* (VU). In this area the rivers Kemijoki and Simojoki streams into the Gulf of Bothnia. The rivers and the coastline itself provide suitable habitats for many species in forms of shores and different meadow types. Such habitats are usually suitable for species with higher demands on their habitat, which could explain a part of the low Red List Index values in this region. My results correspond strongly with Kalpio & Bergman's (1999) findings that there is a "triangle" between Kemi, Rovaniemi and Ylitornio (p. 39 in Kalpio & Bergman 1999) with particularly rich vegetation as a result of a bedrock rich in calcareous rich dolomite and a large amount of different rural biotopes and shores suitable for demanding species. Threatened species that occur in this area include e.g. *Botrychium virginianum* (EN), *Persicaria foliosa* (EN) and *Malaxis monophyllos* (EN) (Ryttäri et al. 2012).

North Karelia resembles Oulanka as it too is a place where southern and northern elemets of the Finnish flora meet. In particular, Koli national park with its herb-rich forests, special microclimate and varying bedrock (e.g. calcareous areas) and topography, is an important area (Hokkanen 2003). Many species like *Epilobium alsinifolium, Eriophorum gracile* and *Selaginella selaginoides* have their southernmost distribution here. On the contrary, *Epilobium collinum, Gymnadenia conopsea* var. *conopsea* and *Rosa acicularis* have their northernmost distribution in Finland in North Karelia. Koli is also home to some eastern species (e.g. *Diplazium sibiricum*). The hills that are untypical for the rest of southern and central Finland provide the Koli region with vastly different habitats that suit both southern and northern species with completely different demands on their environment. Between the exposed hills lie protected valleys and the humid eastern slopes favor a rich flora whereas on the western slopes the microclimate is completely different (Hokkanen 2003). According to Hokkanen (2003) the Koli area is "valuable for maintaining threatened forest flora and eastern elements" in the Finnish flora. My results support this as the Red List Index values were significantly lower than could be expected by chance.

The other smaller areas with low Red List Index values are almost all situated at areas with calcareous bedrock or are sited in the far north with subarctic flora (Fig. 16). Thus, the same causes are likely behind the lower Red List Index values here as in the bigger "hot spot" areas.

The taxonomic Red List Index was lower than expected by chance along the coast and also in southern Finland in general. This is supported by Aapala et al. (2017) who found that the forests in southern Finland have higher protection values than forests in northern Finland due to a higher biodiversity and higher numbers of threatened species. The situation for southern Finland is worsened by the fact that most of the protected areas in Finland are situated in northern Finland (e.g. Mikkonen 2013; Aapala et al. 2017). Thus, there is a mismatch between those areas that would need to be protected and have low Red List Index values and where the protected areas de facto are. In addition, most protected areas in southern Finland are small and heavily fragmented thus creating an extinction debt (Hanski & Ovaskainen 2002; Mikkonen 2013). Therefore, it is likely that the Red List Index values in southern Finland will continue to decline in the future.

4.3.2 Sites with high Red List Index values

The highest Red List Index values were found in South and Central Ostrobothnia and in Lapland (except from the most northern parts of Lapland). High Red List Index values mean an abundance of species categorized as LC in the threat assessments and only few species categorized as either NT, VU, EN, CR or RE. In Lapland, the high Red List Index values are probably due to a relatively low species diversity in the boreal forests that dominate this part of Finland. Most threatened and more demanding species in Lapland are bound to specific habitats with richer vegetation and these areas again can be seen as small patches of areas with lower Red List Index values (Fig. 10 & 14).

In Central Ostrobothnia, the forests have been used increasingly efficiently already from the 18th century – first tar was exported, during the 19th and 20th century shipbuilding and sawmill industry bloomed and after that, until this day, forestry is still extensive. This long forest management history in combination with the area being rather homogenous and barren has affected the flora of the region (Aho 1968). According to Leikola (1999) the forests of South Ostrobothnia differ from the rest of forests in southern Finland in that they are barren and a

long forestry history that has led to many species declining in this area in a similar fashion as in Central Ostrobothnia.

Centuries of forest management in both South and Central Ostrobothnia might have led to local extinctions and loss of biodiversity already long before red listing measures began in Finland in the 1980s which would explain the high Red List Index values for this area today. Overall, the Red List Index was negatively correlated to agro-forestry areas. In Ostrobothnia, however this negative correlation does no longer exist probably due to the long forest management history that has already decreased the biodiversity on local and regional scales. Agro-forestry areas where positively correlated to functional diversity (Table 8) meaning that managed forests might capture more functional diversity than forests in natural condition but at the same time the extinction risk is higher in these landscapes.

In addition to a long history of forest management, the landscape in Ostrobothnia is far more cultivated and the forests are more fragmented than in eastern Finland. Lack of variety in bedrock, soil and topography and extensive loss of old forests and mires further explains why so few threatened species occur in South and Central Ostrobothnia. This explains the high Red List Index values for this region. There are simply no habitats for the more demanding vascular plant species that often also are threatened and thus, the region is dominated by common (least concern) species. This means that high Red List Index values do not necessarily tell the whole truth. Instead, the present high Red List Index values do not reveal the decline in species richness that has happened already some decades ago.

4.5 Limitations to the results and future work

I used functional trait data from international databases. Therefore, it is of course possible that not all data suits Finnish conditions perfectly. For instance, plant maximum height is most likely heavily influenced by the surrounding environment and climate so maximum plant for a certain species measured in Germany might not be the same if the measurement were done in Finland. The choice of traits could also have affected the results. However, I examined over 50 scientific papers when choosing the traits and followed instructions made by among others Cornelissen et al. (2003) so there was a strong basis in the ecological literature for the choice of traits.

All my results are based on the species distribution models I made. As I mentioned in the Materials & Methods section I think that the species distribution models represent better distribution maps than maps based solely on the records in Kastikka database would be. I used the same environmental conditions as most other papers have used. Niittynen & Luoto (2017) proved in a study in northern Norway that snow cover was the most influential factor predicting arctic species distribution on local scales. Adding snow cover to my thesis might have further improved my SDMs. Conclusively, as my thesis focuses on a rather big area (Finland) I believe that possible, small errors in the SDM: s do not affect the results on the big scale.

With 1194 species and a grid system with 8733 cells, the data sets were rather big in this thesis. Thus, several interesting things were left untouched for now. For instance, further analyzing in the differencies between the taxonomic and functional Red List Index could be done. Correlations and statistical significance could be calculated for the relationship between calcareous bedrocks and low Red List Index values (both taxonomic and functional Red List Index). This could yield useful information on just how important the calcareous areas are for our taxonomic and functional diversity in Finland.

This thesis is based on the Finnish red list 2010. In 2019 a new red list is to be published. As the Red List Index is a tool meant for analyzing extinction risks over time it would be important to "re-do" this work with the data in the 2019 version of the red list. Then the development of the extinction risk for vascular plants across Finland would be revealed. It would also be possible to do this work with the red list assessment from 2000 to be able to see how the extinction risk has developed.

The goal for this thesis was originally to calculate a functionally weighted Red List Index based on the functional tree I created. However, due to timetable constraints this part was left out from the thesis. In future studies, it would be very interesting to compare my results with a functional Red List Index. This would also solve the problem of the Red List Index being focused only on taxonomic diversity and disregardning all other forms of diversity. Further, the phylogenetic dimension of the Red List Index could be added to compare three dimensions of biodiversity, instead of two. Phylogenetic data needed for this can easily be obtained from databases online. Conclusively, there are still plenty of data and opportunities to be studied in this field.

5. CONCLUSIONS

Taxonomic diversity was highest in southern Finland and followed a latitudinal gradient decreasing towards the north. Functional diversity also followed very closely the same patterns observed for taxonomic diversity. Thus, it seems that they are affected by the same environmental variables.

Null models indicate that the uneven distribution of functional diversity is caused by environmental filtering in the north and east, excluding species that do not have the right set of traits for the more harsh environmental conditions there. Thus, the only species that survive there have adapted to the environment and have similar functional traits decreasing the overall functional diversity in northern and eastern Finland even taking the lower species richness into account. In southern Finland on the contrary, the environmental conditions are more favourable, which is shown as a high taxonomic diversity that drives interspecific competition. Competitive exclusion has excluded functionally similar species from co-existing and resulted in a wider trait divergence to avoid competition between species. This has led to a high functional diversity.

The Red List Index was mapped for the whole Finland for 10 x 10 km cells. The Red List Index was calculated for both taxonomic and functional diversity. The taxonomic Red List Index was lowest in southern Finland along the coast and escpecially in the southwestern archipelago (Åland islands), Kilpisjärvi, in Kemi-area, Kuusamo and parts of North Karelia and on a few other hot spot areas. What these areas had in common was a calcareouces bedrock, a varying topography and that many of the places are sited at geographically extreme places – either in the far north, or far south or far in the east. These prospects explain the rich flora these sites have and the high amount of threatened and near threatened species which explain the observed low Red List Index values.

The Red List Index is a tool meant for tracking extinction risks over time. Therefore, my results on their own tell little about the actual trends. When the new red list for Finland is published in 2019 it would be useful to re-do these analyses with the new threat assessment to see how extinction risk has developed. It would especially important to examine changes in the vulnerable hot spot areas but also to make sure that areas that now scored high taxonomic and functional Red List Index values do not deteriorate. This thesis showed that the Red List Index

can be used to map the extinction risks on a large scale to be able to examine the extinction risks at local scales.

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8. APPENDICES

SUPPLEMENTARY TABLE 1. A summarization of the five IUCN criteria (table modified from Ryttäri et al. 2012). Threatened species fulfill at least one of the criteria. For the full criteria used in Finland, see Liukko et al. 2017.

A)	Reduction of population size Examines how fast the population is declining (> 30 % → VU, > 50 % → EN, > 80 % → CR) under a certain time period that is species specific.
B)	Geographic range; extent of occurrence (B1) or area of occupancy (B2) The geographic range is small. Depending on the species wither criteria B1 or B2 is used. B1) Extent of occurrence < 20000 km² → VU, < 5000 km² → EN, < 100 km² → CR. B2) Area of occupancy < 2000 km² → VU, < 500 km² → EN, < 10 km² → CR. Further, the species geographic range is heavily fragmented, the population undergoes continuing decline or extreme fluctuations in area of occupancy or number of reproductive individuals.
C)	Small and continuously declining population The population is small and continuously declining. The number of reproductive individuals in the population is < 10000 → VU, < 2500 → EN, < 250 → CR.
D)	Very small or restricted population The population size is small or the area of occupancy is very restricted. One of the two criteria has to be fulfilled. D1: The number of reproductive individuals is < 1000 → VU, < 250 → EN, < 50 → CR. Or: D2: The area of occupancy is very restricted (< 20 km²) or the species occurs on five or fewer locations, which means that the species is very vulnerable to stochastic events and/or anthropogenic activity. Therefore, the extinction risk is so high that the species might be categorized as CR or EX in a very short period of time.
E)	**Quantitative analysis** The probabilty that the species goes extinct during a certain period of time. - Probability of extinction is 10 % within 100 years → VU. - Probability of extinction is 20 % within 20 years, or five generations → EN. - Probability of extinction is 50 % within 10 years, or three generations → CR. Criteria E has not been used for Finnish vascular plants.

SUPPLEMENTARY TABLE 2. List of species. All 1194 species in the list were used for taxonomic diversity and Red List Index. The species threat categories from the 2010 Finnish Red List (Rassi et al. 2010) is given and all (971) species marked “yes” were used for functional diversity.

Species	**Threat category 2010**	**Included in Functional Diversity**
Acer platanoides	LC	yes
Achillea millefolium	LC	yes
Achillea ptarmica	LC	yes
Aconitum lycoctonum subsp. septentrionale	VU	yes
Actaea erythrocarpa	LC	yes
Actaea spicata	LC	yes
Adoxa moschatellina	LC	yes
Aegopodium podagraria	LC	yes
Aethusa cynapium	LC	yes
Agrimonia eupatoria	LC	yes
Agrimonia pilosa	EN	yes
Agrimonia procera	LC	yes
Agrostis canina	LC	yes
Agrostis capillaris	LC	yes
Agrostis clavata	VU	yes
Agrostis gigantea	LC	yes
Agrostis mertensii	LC	yes
Agrostis stolonifera	LC	yes
Agrostis vinealis	LC	yes
Aira praecox	NT	yes
Ajuga pyramidalis	NT	yes
Alchemilla acutiloba	LC	yes
Alchemilla alpina	LC	yes
Alchemilla baltica	LC	yes
Alchemilla borealis	LC	yes
Alchemilla filicaulis	LC	yes
Alchemilla glabra	LC	yes
Alchemilla glaucescens	LC	yes
Alchemilla glomerulans	LC	yes
Alchemilla hirsuticaulis	VU	yes
Alchemilla micans	LC	yes
Alchemilla monticola	LC	yes
Alchemilla murbeckiana	LC	yes
Alchemilla plicata	NT	yes
Alchemilla propinqua	NT	yes
Alchemilla samuelssonii	NT	yes
Alchemilla subcrenata	LC	yes
Alchemilla wichurae	LC	yes
Alisma plantago-aquatica	LC	yes
Alisma wahlenbergii	EN	yes
Alliaria petiolata	LC	yes

Allium oleraceum	LC	yes
Allium schoenoprasum subsp. alpinum	NT	yes
Allium schoenoprasum subsp. schoenoprasum	LC	yes
Allium scorodoprasum	LC	yes
Allium ursinum	NT	yes
Allium vineale	LC	yes
Alnus glutinosa	LC	yes
Alnus incana	LC	yes
Alopecurus aequalis	LC	yes
Alopecurus arundinaceus	LC	yes
Alopecurus geniculatus	LC	yes
Alopecurus pratensis	LC	yes
Ammophila arenaria	EN	yes
Anagallis minima	EN	yes
Anchusa officinalis	NT	yes
Andromeda polifolia	LC	no
Androsace septentrionalis	EN	no
Anemone nemorosa	LC	yes
Anemone ranunculoides	LC	yes
Anemone trifolia	VU	yes
Angelica archangelica subsp. archangelica	LC	yes
Angelica archangelica subsp. litoralis	LC	yes
Angelica sylvestris	LC	yes
Antennaria alpina	LC	yes
Antennaria canescens	LC	yes
Antennaria dioica	NT	yes
Antennaria nordhageniana	VU	yes
Antennaria porsildii	VU	yes
Antennaria villifera	NT	yes
Anthemis tinctoria	LC	yes
Anthoxanthum alpinum	LC	yes
Anthoxanthum odoratum	LC	yes
Anthriscus sylvestris	LC	yes
Anthyllis vulneraria subsp. lapponica	NT	yes
Anthyllis vulneraria subsp. polyphylla	CR	yes
Anthyllis vulneraria subsp. vulneraria	LC	yes
Aquilegia vulgaris	LC	yes
Arabidopsis suecica	LC	yes
Arabidopsis thaliana	LC	yes
Arabis alpina	LC	yes
Arabis glabra	LC	yes
Arabis hirsuta	LC	yes
Arctagrostis latifolia	NT	no
Arctium lappa	LC	yes
Arctium minus	LC	yes
Arctium nemorosum	EN	yes
Arctium tomentosum	LC	yes
Arctophila fulva var. pendulina	EN	no
Arctostaphylos alpina	LC	yes
Arctostaphylos uva-ursi	LC	yes
Arenaria norvegica	VU	no
Arenaria pseudofrigida	LC	no
Arenaria serpyllifolia	LC	yes
Armeria maritima subsp. elongata	EN	no
Armeria maritima subsp. intermedia	CR	no
Armeria maritima subsp. sibirica	EN	no

Arnica angustifolia	EN	no
Arrhenatherum elatius	LC	yes
Artemisia absinthium	LC	yes
Artemisia campestris subsp. bottnica	CR	yes
Artemisia campestris subsp. campestris	LC	yes
Artemisia vulgaris var. coarctata	LC	yes
Artemisia vulgaris var. vulgaris	LC	yes
Asarum europaeum	NT	yes
Asperula tinctoria	CR	yes
Asplenium adulterinum	VU	no
Asplenium ruta-muraria	EN	no
Asplenium septentrionale	LC	no
Asplenium trichomanes subsp. quadrivalens	NT	no
Asplenium trichomanes subsp. trichomanes	LC	no
Asplenium viride	LC	no
Aster tripolium	LC	yes
Astragalus alpinus subsp. arcticus	LC	yes
Astragalus frigidus	LC	yes
Astragalus glycyphyllos	CR	yes
Athyrium distentifolium	LC	no
Athyrium filix-femina	LC	no
Atriplex calotheca	LC	yes
Atriplex glabriuscula	NT	yes
Atriplex littoralis	LC	yes
Atriplex longipes subsp. longipes	LC	yes
Atriplex longipes subsp. praecox	LC	yes
Atriplex patula	LC	yes
Atriplex prostrata	LC	yes
Avenula pratensis	LC	yes
Avenula pubescens	LC	yes
Barbarea stricta	LC	yes
Bartsia alpina	LC	yes
Betula nana	LC	yes
Betula pendula	LC	yes
Betula pubescens subsp. czerepanovii	LC	yes
Betula pubescens subsp. pubescens	LC	yes
Bidens cernua	LC	yes
Bidens radiata	LC	yes
Bidens tripartita	LC	yes
Bistorta vivipara	LC	no
Blysmus compressus	VU	no
Blysmus rufus	NT	no
Bolboschoenus maritimus	LC	no
Botrychium boreale	VU	no
Botrychium lanceolatum	VU	no
Botrychium lunaria	NT	no
Botrychium matricariifolium	EN	no
Botrychium multifidum	NT	no
Botrychium simplex	CR	no
Botrychium virginianum	EN	no
Brachypodium pinnatum	LC	yes
Brachypodium sylvaticum	LC	yes
Brassica rapa subsp. oleifera	LC	yes
Briza media	LC	yes
Bromus benekenii	CR	yes
Bromus hordeaceus	LC	yes

Butomus umbellatus	LC	yes
Cakile maritima subsp. baltica	LC	no
Calamagrostis arundinacea	LC	yes
Calamagrostis canescens	LC	yes
Calamagrostis epigejos	LC	yes
Calamagrostis lapponica	LC	yes
Calamagrostis phragmitoides	LC	no
Calamagrostis stricta	LC	yes
Calla palustris	LC	no
Callitriche cophocarpa	LC	yes
Callitriche hamulata	LC	yes
Callitriche hermaphroditica	LC	yes
Callitriche palustris	LC	yes
Calluna vulgaris	LC	yes
Caltha palustris subsp. palustris	LC	yes
Caltha palustris subsp. radicans	LC	yes
Calypso bulbosa	VU	no
Calystegia sepium subsp. sepium	LC	yes
Campanula cervicaria	VU	yes
Campanula glomerata	LC	yes
Campanula patula	LC	yes
Campanula persicifolia	LC	yes
Campanula rapunculoides	LC	yes
Campanula rotundifolia subsp. gieseckiana	NT	yes
Campanula rotundifolia subsp. groenlandica	LC	yes
Campanula rotundifolia subsp. rotundifolia	LC	yes
Campanula trachelium	LC	yes

Campanula uniflora	VU	yes
Capsella bursa.pastoris	LC	yes
Cardamine amara	LC	yes
Cardamine bellidifolia	LC	yes
Cardamine flexuosa	EN	yes
Cardamine hirsuta	LC	yes
Cardamine impatiens	EN	yes
Cardamine parviflora	EN	yes
Cardamine pratensis subsp. paludosa	LC	yes
Cardamine pratensis subsp. polemonioides	LC	yes
Cardamine pratensis subsp. pratensis	NT	yes
Carduus crispus	LC	yes
Carex acuta	LC	yes
Carex acutiformis	NT	yes
Carex appropinquata	VU	yes
Carex aquatilis	LC	yes
Carex arctogena	LC	no
Carex arenaria	NT	yes
Carex atherodes	NT	no
Carex atrata	NT	yes
Carex atrofusca	NT	yes
Carex bigelowii subsp. Rigida	LC	yes
Carex bohemica	VU	yes
Carex brunnescens	LC	yes
Carex buxbaumii subsp. buxbaumii	LC	yes
Carex buxbaumii subsp. mutica	LC	yes
Carex canescens	LC	yes
Carex capillaris	LC	yes

Carex capitata	LC	yes
Carex caryophyllea	VU	yes
Carex cespitosa	LC	yes
Carex chordorrhiza	LC	yes
Carex demissa	LC	yes
Carex diandra	LC	yes
Carex digitata	LC	yes
Carex dioica	LC	yes
Carex disperma	NT	yes
Carex distans	LC	yes
Carex disticha	LC	yes
Carex echinata	LC	yes
Carex elata subsp. elata	LC	yes
Carex elata subsp. omskiana	LC	yes
Carex elongata	LC	yes
Carex ericetorum	LC	yes
Carex extensa	NT	yes
Carex flacca	LC	yes
Carex flava	LC	yes
Carex fuliginosa subsp. misandra	NT	yes
Carex glacialis	LC	yes
Carex glareosa	NT	no
Carex globularis	LC	no
Carex halophila	LC	no
Carex hartmanii	EN	no
Carex heleonastes	VU	yes
Carex hirta	LC	yes
Carex holostoma	LC	yes
Carex hostiana	EN	yes

Carex lachenalii	LC	yes
Carex lapponica	LC	yes
Carex lasiocarpa	LC	yes
Carex laxa	NT	yes
Carex lepidocarpa subsp. jemtlandica	VU	yes
Carex lepidocarpa subsp. lepidocarpa	EN	yes
Carex leporina	LC	yes
Carex limosa	LC	yes
Carex livida	LC	yes
Carex loliacea	LC	yes
Carex mackenziei	LC	yes
Carex macloviana	LC	yes
Carex maritima	EX	yes
Carex microglochin	EN	yes
Carex montana	EX	yes
Carex muricata	LC	yes
Carex nigra subsp. juncella	LC	yes
Carex nigra subsp. nigra	LC	yes
Carex norvegica subsp. inferalpina	LC	yes
Carex norvegica subsp. norvegica	LC	yes
Carex ornithopoda	CR	yes
Carex otrubae	VU	yes
Carex paleacea	NT	yes
Carex pallescens	LC	yes
Carex pallidula	LC	yes
Carex panicea	LC	yes
Carex paniculata	EN	yes
Carex parallela	LC	yes
Carex pauciflora	LC	yes

Carex paupercula	LC	yes
Carex pediformis subsp. rhizodes	LC	yes
Carex pilulifera	LC	yes
Carex pseudocyperus	LC	yes
Carex pulicaris	VU	yes
Carex rariflora	LC	yes
Carex remota	EN	yes
Carex rhynchophysa	NT	yes
Carex riparia	NT	yes
Carex rostrata	LC	yes
Carex rotundata	LC	yes
Carex rupestris	NT	yes
Carex saxatilis	LC	yes
Carex spicata	LC	yes
Carex stenolepis	LC	yes
Carex tenuiflora	LC	yes
Carex vaginata	LC	yes
Carex vesicaria	LC	yes
Carex viridula var. bergrothii	VU	yes
Carex viridula var. pulchella	LC	yes
Carex viridula var. viridula	LC	yes
Carex vulpina	EN	yes
Carlina biebersteinii	EN	yes
Carlina vulgaris	VU	yes
Carum carvi	LC	no
Cassiope hypnoides	LC	no
Cassiope tetragona	LC	no
Catabrosa aquatica	NT	no
Centaurea cyanus	LC	yes

Centaurea jacea	LC	yes
Centaurea phrygia	LC	yes
Centaurea scabiosa	LC	yes
Centaurium littorale	LC	yes
Centaurium pulchellum	NT	yes
Cephalanthera longifolia	NT	no
Cephalanthera rubra	CR	no
Cerastium alpinum (Kaavin serpentiinirotu)	EN	no
Cerastium alpinum	NT	no
Cerastium alpinum subsp. alpinum	LC	yes
Cerastium alpinum subsp. glabratum	LC	yes
Cerastium alpinum subsp. lanatum	LC	yes
Cerastium cerastoides	LC	yes
Cerastium fontanum subsp. fontanum	LC	yes
Cerastium fontanum subsp. vulgare var. kajanense	EN	yes
Cerastium fontanum subsp. vulgare var. vulgare	LC	yes
Cerastium glutinosum	NT	no
Cerastium nigrescens var. laxum	NT	yes
Cerastium semidecandrum	LC	yes
Ceratophyllum demersum	LC	no
Chamaedaphne calyculata	LC	no
Chamorchis alpina	EN	no
Chelidonium majus	LC	no
Chenopodium album	LC	yes
Chenopodium glaucum	LC	yes
Chenopodium polyspermum	LC	yes
Chenopodium rubrum	LC	yes

Chenopodium suecicum	LC	yes
Chimaphila umbellata	NT	no
Chrysosplenium alternifolium	LC	yes
Chrysosplenium tetrandrum	LC	yes
Cicerbita alpina	LC	yes
Cicuta virosa	LC	yes
Cinna latifolia	NT	no
Circaea alpina	LC	yes
Cirsium arvense	LC	yes
Cirsium helenioides	LC	yes
Cirsium oleraceum	VU	yes
Cirsium palustre	LC	yes
Cirsium vulgare	LC	yes
Cladium mariscus	EN	yes
Clematis alpina subsp. sibirica	VU	yes
Cochlearia danica	LC	yes
Coeloglossum viride	LC	no
Comarum palustre	LC	no
Conium maculatum	LC	yes
Convallaria majalis	LC	yes
Convolvulus arvensis	LC	yes
Corallorhiza trifida	LC	no
Cornus suecica	LC	yes
Corydalis intermedia	LC	yes
Corydalis solida	LC	yes
Corylus avellana	LC	yes
Cotoneaster scandinavicus	LC	no
Crambe maritima	LC	no
Crassula aquatica	VU	yes

Crataegus monogyna	VU	yes
Crataegus rhipidophylla	VU	no
Crepis paludosa	LC	yes
Crepis praemorsa	EN	yes
Crepis tectorum subsp. nigrescens	EN	yes
Crepis tectorum subsp. tectorum	LC	yes
Cryptogramma crispa	LC	no
Cuscuta europaea subsp. europaea	LC	no
Cuscuta europaea subsp. halophyta	LC	no
Cynoglossum officinale	NT	yes
Cynosurus cristatus	LC	yes
Cypripedium calceolus	NT	no
Cystopteris fragilis subsp. dickieana	LC	no
Cystopteris fragilis subsp. fragilis	LC	no
Cystopteris montana	LC	no
Dactylis glomerata	LC	yes
Dactylorhiza fuchsii	NT	yes
Dactylorhiza incarnata subsp. cruenta	VU	yes
Dactylorhiza incarnata subsp. incarnata	VU	yes
Dactylorhiza lapponica	VU	yes
Dactylorhiza maculata	LC	yes
Dactylorhiza majalis subsp. baltica	CR	yes
Dactylorhiza sambucina	NT	yes
Dactylorhiza traunsteineri	VU	yes
Danthonia decumbens	LC	yes
Daphne mezereum	LC	yes
Dentaria bulbifera	LC	no
Deschampsia alpina	LC	yes
Deschampsia bottnica	LC	yes

Deschampsia cespitosa	LC	yes
Deschampsia flexuosa	LC	yes
Descurainia sophia	LC	yes
Dianthus arenarius subsp. borussicus	EN	yes
Dianthus deltoides	NT	yes
Dianthus superbus (Kaavin serpentiinirotu)	CR	yes
Dianthus superbus	LC	yes
Diapensia lapponica	LC	no
Diphasiastrum alpinum	LC	no
Diphasiastrum complanatum subsp. complanatum	LC	no
Diphasiastrum complanatum subsp. montellii	LC	no
Diphasiastrum tristachyum	EN	no
Diplazium sibiricum	LC	no
Draba alpina	EN	yes
Draba cinerea	VU	yes
Draba daurica	VU	yes
Draba fladnizensis	VU	yes
Draba incana	LC	yes
Draba lactea	VU	yes
Draba muralis	NT	yes
Draba nemorosa	EN	yes
Draba nivalis	NT	yes
Draba norvegica	LC	yes
Drosera intermedia	VU	yes
Drosera longifolia	LC	yes
Drosera rotundifolia	LC	yes
Dryas octopetala	LC	yes

Dryopteris carthusiana	LC	no
Dryopteris cristata	LC	no
Dryopteris dilatata	LC	no
Dryopteris expansa	LC	no
Dryopteris filix.mas	LC	no
Dryopteris fragrans	NT	no
Elatine alsinastrum	EN	no
Elatine hydropiper	LC	no
Elatine orthosperma	LC	no
Elatine triandra	LC	no
Eleocharis acicularis	LC	yes
Eleocharis mamillata	LC	no
Eleocharis palustris	LC	yes
Eleocharis parvula	LC	yes
Eleocharis quinqueflora	LC	yes
Eleocharis uniglumis var. fennica	LC	yes
Elymus caninus	LC	yes
Elymus farctus subsp. boreoatlanticus	VU	yes
Elymus fibrosus	VU	yes
Elymus kronokensis subsp. scandicus	NT	yes
Elymus mutabilis	LC	yes
Elymus repens subsp. arenosus	LC	yes
Elymus repens subsp. repens	LC	yes
Empetrum nigrum subsp. hermaphroditum	LC	yes
Empetrum nigrum subsp. nigrum	LC	yes
Epilobium alsinifolium	LC	yes
Epilobium anagallidifolium	LC	yes
Epilobium angustifolium	LC	yes

Epilobium collinum	LC	yes
Epilobium davuricum	LC	yes
Epilobium hornemannii	LC	yes
Epilobium lactiflorum	LC	yes
Epilobium laestadii	EN	yes
Epilobium lamyi	EN	yes
Epilobium montanum	LC	yes
Epilobium obscurum	EN	yes
Epilobium palustre	LC	yes
Epilobium parviflorum	LC	yes
Epipactis atrorubens	VU	yes
Epipactis helleborine	LC	yes
Epipactis palustris	EN	yes
Epipogium aphyllum	VU	no
Equisetum arvense subsp. boreale	LC	no
Equisetum fluviatile	LC	no
Equisetum hyemale	LC	no
Equisetum palustre	LC	no
Equisetum pratense	LC	no
Equisetum scirpoides	LC	no
Equisetum sylvaticum	LC	no
Equisetum variegatum	LC	no
Erica tetralix	CR	yes
Erigeron acris subsp. decoloratus	VU	yes
Erigeron acris subsp. acris	LC	yes
Erigeron acris subsp. droebachiensis	LC	yes
Erigeron acris subsp. politus	LC	yes
Erigeron borealis	VU	yes
Erigeron humilis	NT	yes
Erigeron uniflorus subsp. eriocephalus	NT	yes
Erigeron uniflorus subsp. uniflorus	LC	yes
Eriophorum angustifolium	LC	yes
Eriophorum brachyantherum	VU	yes
Eriophorum gracile	LC	yes
Eriophorum latifolium	LC	yes
Eriophorum russeolum	LC	yes
Eriophorum scheuchzeri	LC	yes
Eriophorum vaginatum	LC	yes
Erophila verna	LC	yes
Erysimum cheiranthoides subsp. altum	LC	yes
Erysimum cheiranthoides subsp. cheiranthoides	LC	yes
Erysimum strictum	LC	yes
Eupatorium cannabinum	LC	yes
Euphorbia palustris	LC	yes
Euphrasia bottnica	NT	yes
Euphrasia frigida	LC	yes
Euphrasia micrantha	EN	yes
Euphrasia nemorosa	LC	yes
Euphrasia rostkoviana subsp. fennica	EN	yes
Euphrasia salisburgensis	EN	yes
Euphrasia stricta var. brevipila	LC	yes
Euphrasia stricta var. tenuis	LC	yes
Fallopia convolvulus	LC	yes
Fallopia dumetorum	LC	yes
Festuca arundinacea	LC	yes
Festuca gigantea	EN	yes
Festuca ovina	LC	yes

Festuca polesica	NT	yes
Festuca pratensis	LC	yes
Festuca rubra subsp. arctica	LC	yes
Festuca rubra subsp	LC	yes
Festuca vivipara	LC	yes
Filago arvensis	LC	yes
Filipendula ulmaria	LC	yes
Filipendula vulgaris	LC	yes
Fragaria vesca	LC	yes
Fragaria viridis	VU	yes
Fraxinus excelsior	LC	yes
Fumaria officinalis	LC	yes
Gagea lutea	LC	yes
Gagea minima	LC	yes
Galeopsis bifida	LC	yes
Galeopsis ladanum	NT	yes
Galeopsis speciosa	LC	yes
Galeopsis tetrahit	LC	yes
Galium album	LC	yes
Galium aparine	LC	yes
Galium boreale	LC	yes
Galium odoratum	NT	yes
Galium palustre subsp. elongatum	LC	yes
Galium palustre subsp. palustre	LC	yes
Galium saxatile	EN	yes
Galium schultesii	CR	yes
Galium spurium subsp. vaillantii	LC	no
Galium trifidum	LC	yes
Galium triflorum	LC	yes

Galium uliginosum	LC	yes
Galium verum	VU	yes
Gentiana nivalis	LC	yes
Gentianella amarella	EN	yes
Gentianella campestris	EN	yes
Gentianella tenella	EN	yes
Gentianella uliginosa	EN	yes
Geranium bohemicum	NT	yes
Geranium dissectum	EN	yes
Geranium lucidum	LC	yes
Geranium molle	LC	yes
Geranium palustre	LC	yes
Geranium pusillum	LC	yes
Geranium robertianum	LC	yes
Geranium sanguineum	LC	yes
Geranium sylvaticum	LC	yes
Geum aleppicum	NT	yes
Geum rivale	LC	yes
Geum urbanum	LC	yes
Glaux maritima	LC	no
Glechoma hederacea	LC	yes
Glyceria fluitans	LC	yes
Glyceria lithuanica	LC	yes
Glyceria notata	LC	yes
Gnaphalium norvegicum	LC	no
Gnaphalium supinum	LC	no
Gnaphalium sylvaticum	LC	no
Gnaphalium uliginosum	LC	no
Goodyera repens	LC	no

Gymnadenia conopsea var. conopsea	VU	yes
Gymnadenia conopsea var. lapponica	LC	yes
Gymnocarpium continentale	NT	no
Gymnocarpium dryopteris	LC	no
Gymnocarpium robertianum	LC	no
Gypsophila fastigiata	EN	no
Gypsophila muralis	VU	no
Hammarbya paludosa	NT	no
Helianthemum nummularium	NT	yes
Hepatica nobilis	LC	yes
Heracleum sibiricum var. sibiricum	LC	yes
Herminium monorchis	EX	no
Hierochloe alpina	LC	no
Hierochloe australis	LC	no
Hierochloe hirta	LC	no
Hierochloe odorata subsp. baltica	LC	no
Hippophae rhamnoides	LC	yes
Hippuris tetraphylla	EN	no
Hippuris vulgaris	LC	no
Honckenya peploides	LC	no
Humulus lupulus	LC	yes
Huperzia selago	LC	no
Hydrocharis morsus-ranae	LC	no
Hypericum hirsutum	LC	yes
Hypericum maculatum	LC	yes
Hypericum montanum	CR	yes
Hypericum perforatum	LC	yes
Hypochoeris maculata	LC	yes
Impatiens noli-tangere	LC	yes

Inula salicina	LC	yes
Iris pseudacorus	LC	yes
Isatis tinctoria	LC	no
Isoetes echinospora	LC	no
Isoetes lacustris	LC	no
Jasione montana	VU	yes
Juncus alpinoarticulatus subsp. alpestris	LC	yes
Juncus alpinoarticulatus subsp. alpinoarticulatus	LC	yes
Juncus alpinoarticulatus subsp. fischerianus	LC	yes
Juncus alpinoarticulatus subsp. rariflorus	LC	yes
Juncus arcticus	EN	yes
Juncus articulatus var. articulatus	LC	yes
Juncus articulatus var. hylandri	LC	yes
Juncus balticus	LC	yes
Juncus biglumis	LC	yes
Juncus bufonius subsp. bufonius	LC	yes
Juncus bufonius subsp. ranarius	LC	yes
Juncus bulbosus	LC	yes
Juncus compressus	LC	yes
Juncus conglomeratus	LC	yes
Juncus effusus	LC	yes
Juncus filiformis	LC	yes
Juncus gerardii	LC	yes
Juncus stygius	LC	yes
Juncus trifidus	LC	yes
Juncus triglumis	LC	yes
Juniperus communis	LC	yes

Knautia arvensis	LC	yes
Kobresia myosuroides	CR	no
Kobresia simpliciuscula	EN	no
Koenigia islandica	NT	no
Lactuca sibirica	LC	yes
Lamium album	LC	yes
Lamium amplexicaule	LC	yes
Lamium confertum	LC	yes
Lamium hybridum	LC	yes
Lamium purpureum	LC	yes
Lappula deflexa	VU	yes
Lapsana communis	LC	yes
Laserpitium latifolium	LC	no
Lathraea squamaria	VU	no
Lathyrus japonicus subsp. maritimus	LC	yes
Lathyrus linifolius	LC	yes
Lathyrus niger	LC	yes
Lathyrus palustris	LC	yes
Lathyrus pratensis	LC	yes
Lathyrus sylvestris	LC	yes
Lathyrus vernus	LC	yes
Ledum palustre	LC	no
Leersia oryzoides	VU	no
Lemna gibba	LC	no
Lemna minor	LC	no
Lemna trisulca	LC	no
Leontodon autumnalis	LC	yes
Leontodon hispidus	NT	yes
Lepidium latifolium	NT	yes

Lepidium ruderale	LC	yes
Leucanthemum vulgare	LC	yes
Leymus arenarius	LC	yes
Ligusticum scoticum	LC	no
Limosella aquatica	LC	yes
Linaria vulgaris	LC	yes
Linnaea borealis	LC	no
Linum catharticum	LC	yes
Liparis loeselii	CR	no
Listera cordata	LC	no
Listera ovata	LC	no
Lithospermum arvense	EN	yes
Littorella uniflora	LC	yes
Lobelia dortmanna	LC	no
Loiseleuria procumbens	LC	no
Lonicera caerulea	EN	yes
Lonicera xylosteum	LC	yes
Lotus corniculatus	LC	yes
Luzula arcuata subsp. arcuata	LC	no
Luzula arcuata subsp. confusa	LC	no
Luzula campestris	LC	yes
Luzula multiflora subsp. frigida	LC	yes
Luzula multiflora subsp. multiflora	LC	yes
Luzula pallescens	LC	yes
Luzula parviflora	LC	yes
Luzula pilosa	LC	yes
Luzula spicata	LC	yes
Luzula sudetica	LC	yes
Luzula wahlenbergii	LC	yes

Lychnis alpina var. alpina	LC	yes
Lychnis alpina var. serpentinicola	NT	yes
Lychnis flos-cuculi	LC	yes
Lychnis viscaria	LC	yes
Lycopodiella inundata	NT	no
Lycopodium annotinum subsp. alpestre	LC	no
Lycopodium annotinum subsp. annotinum	LC	no
Lycopodium clavatum subsp. clavatum	LC	no
Lycopodium clavatum subsp. monostachyon	LC	no
Lycopus europaeus	LC	yes
Lysimachia thyrsiflora	LC	yes
Lysimachia vulgaris	LC	yes
Lythrum portula	VU	yes
Lythrum salicaria	LC	yes
Maianthemum bifolium	LC	yes
Malaxis monophyllos	EN	no
Malus sylvestris	VU	yes
Matricaria chamomilla	LC	yes
Matteuccia struthiopteris	LC	no
Melampyrum arvense	VU	yes
Melampyrum cristatum	VU	yes
Melampyrum nemorosum	LC	yes
Melampyrum pratense	LC	yes
Melampyrum sylvaticum	LC	yes
Melica ciliata	CR	yes
Melica nutans	LC	yes
Melica picta	NT	yes
Melica uniflora	EN	yes
Mentha aquatica var. aquatica	VU	yes
Mentha aquatica var. litoralis	NT	yes
Mentha arvensis	LC	yes
Menyanthes trifoliata	LC	yes
Mercurialis perennis	LC	yes
Milium effusum	LC	yes
Minuartia biflora	LC	yes
Minuartia rubella	VU	yes
Minuartia stricta	VU	yes
Moehringia lateriflora	NT	yes
Moehringia trinervia	LC	yes
Molinia caerulea	LC	yes
Moneses uniflora	LC	no
Monotropa hypopitys subsp. hypophegea	NT	no
Monotropa hypopitys subsp. hypopitys	LC	no
Montia fontana	LC	yes
Mycelis muralis	LC	no
Myosotis arvensis	LC	yes
Myosotis decumbens	LC	yes
Myosotis laxa subsp. baltica	LC	yes
Myosotis laxa subsp. caespitosa	LC	yes
Myosotis nemorosa	NT	yes
Myosotis ramosissima	LC	yes
Myosotis scorpioides	LC	yes
Myosotis stricta	LC	yes
Myosoton aquaticum	LC	yes
Myosurus minimus	LC	no
Myrica gale	LC	yes

Myricaria germanica	NT	no
Myriophyllum alterniflorum	LC	yes
Myriophyllum sibiricum	LC	yes
Myriophyllum spicatum	LC	yes
Myriophyllum verticillatum	LC	yes
Najas flexilis	EN	no
Najas marina subsp	LC	no
Najas tenuissima	EN	no
Nardus stricta	NT	yes
Neottia nidus-avis	LC	no
Nuphar lutea	LC	yes
Nuphar pumila	LC	yes
Nymphaea alba subsp. alba	LC	yes
Nymphaea alba subsp. candida	LC	yes
Nymphaea tetragona	LC	yes
Odontites litoralis subsp. fennicus	LC	yes
Odontites litoralis subsp. litoralis	LC	yes
Odontites vulgaris	LC	yes
Oenanthe aquatica	NT	yes
Ononis arvensis	VU	yes
Ophioglossum vulgatum	LC	no
Ophrys insectifera	EN	no
Orchis mascula	NT	yes
Orchis militaris	EN	yes
Origanum vulgare	LC	yes
Orthilia secunda	LC	no
Oxalis acetosella	LC	yes
Oxyria digyna	LC	no
Oxytropis campestris subsp. sordida	LC	no
Oxytropis lapponica	CR	no
Paris quadrifolia	LC	yes
Parnassia palustris	LC	yes
Pastinaca sativa	LC	yes
Pedicularis hirsuta	NT	yes
Pedicularis lapponica	LC	yes
Pedicularis palustris subsp. borealis	LC	yes
Pedicularis palustris subsp. opsiantha	LC	yes
Pedicularis palustris subsp. palustris	LC	yes
Pedicularis sceptrum-carolinum	LC	yes
Persicaria amphibia	LC	no
Persicaria foliosa	EN	no
Persicaria hydropiper	LC	no
Persicaria lapathifolia	LC	no
Persicaria maculosa	LC	no
Persicaria minor	LC	no
Petasites frigidus	LC	yes
Petasites spurius	CR	yes
Peucedanum palustre	LC	yes
Phalaris arundinacea	LC	yes
Phegopteris connectilis	LC	no
Phippsia algida	NT	no
Phleum alpinum	LC	yes
Phleum phleoides	NT	yes
Phleum pratense subsp. pratense	LC	yes
Phleum pratense subsp. serotinum	NT	yes
Phragmites australis	LC	yes
Phyllodoce caerulea	LC	no
Picea abies subsp. abies	LC	yes

Picea abies subsp. obovata	LC	yes
Picris hieracioides	LC	yes
Pilularia globulifera	VU	no
Pimpinella major	CR	yes
Pimpinella saxifraga	LC	yes
Pinguicula alpina	LC	yes
Pinguicula villosa	LC	yes
Pinguicula vulgaris	LC	yes
Pinus sylvestris	LC	yes
Plantago lanceolata	LC	yes
Plantago major subsp. intermedia	LC	yes
Plantago major subsp	LC	yes
Plantago maritima	LC	yes
Plantago media	LC	yes
Platanthera bifolia subsp. latiflora	LC	yes
Platanthera chlorantha	LC	yes
Platanthera obtusata subsp. oligantha	CR	yes
Poa alpigena	LC	yes
Poa alpina	LC	yes
Poa angustifolia	LC	yes
Poa annua	LC	yes
Poa arctica	LC	yes
Poa compressa subsp. compressa	LC	yes
Poa glauca	LC	yes
Poa humilis	LC	yes
Poa nemoralis	LC	yes
Poa palustris	LC	yes
Poa pratensis	LC	yes
Poa remota	NT	yes
Poa supina	NT	yes
Poa trivialis	LC	yes
Polemonium acutiflorum	LC	yes
Polemonium caeruleum	LC	yes
Polygala amarella	VU	yes
Polygala comosa	EN	yes
Polygala vulgaris	VU	yes
Polygonatum multiflorum	LC	no
Polygonatum odoratum	LC	no
Polygonum aviculare subsp. aviculare	LC	yes
Polygonum aviculare subsp. boreale	LC	yes
Polygonum aviculare subsp. microspermum	LC	yes
Polygonum aviculare subsp. neglectum	LC	yes
Polygonum oxyspermum	CR	yes
Polypodium vulgare	LC	no
Polystichum lonchitis	NT	no
Populus tremula	LC	yes
Potamogeton alpinus	LC	yes
Potamogeton berchtoldii	LC	yes
Potamogeton compressus	LC	yes
Potamogeton crispus	LC	yes
Potamogeton filiformis	LC	yes
Potamogeton friesii	NT	yes
Potamogeton gramineus	LC	yes
Potamogeton lucens	LC	yes
Potamogeton natans	LC	yes
Potamogeton obtusifolius	LC	yes
Potamogeton pectinatus	LC	yes

Potamogeton perfoliatus	LC	yes
Potamogeton polygonifolius	NT	yes
Potamogeton praelongus	LC	yes
Potamogeton pusillus	LC	yes
Potamogeton rutilus	NT	yes
Potamogeton vaginatus	LC	yes
Potentilla anglica	EN	yes
Potentilla anserina subsp. anserina	LC	yes
Potentilla anserina subsp. groenlandica	LC	yes
Potentilla argentea	LC	yes
Potentilla chamissonis	NT	yes
Potentilla crantzii	LC	yes
Potentilla erecta	LC	yes
Potentilla intermedia	LC	yes
Potentilla neumanniana	VU	yes
Potentilla nivea	NT	yes
Potentilla norvegica	LC	yes
Potentilla reptans	LC	yes
Potentilla tabernaemontani	EN	yes
Potentilla thuringiaca	LC	yes
Primula farinosa	EN	yes
Primula nutans subsp. finmarchica	VU	yes
Primula stricta	EN	yes
Primula veris	LC	yes
Prunella vulgaris	LC	yes
Prunus padus subsp. borealis	LC	yes
Prunus padus subsp. padus	LC	yes
Prunus spinosa	NT	yes
Pseudorchis albida subsp. straminea	NT	no

Pteridium aquilinum	LC	no
Puccinellia capillaris	LC	yes
Puccinellia distans	LC	yes
Puccinellia phryganodes	CR	yes
Pulmonaria obscura	LC	yes
Pulsatilla patens	EN	yes
Pulsatilla vernalis	VU	yes
Pyrola chlorantha	LC	yes
Pyrola media	NT	yes
Pyrola minor	LC	yes
Pyrola rotundifolia subsp. norvegica	LC	yes
Pyrola rotundifolia subsp. rotundifolia	LC	yes
Quercus robur	LC	yes
Ranunculus acris subsp. acris	LC	yes
Ranunculus acris subsp. borealis	LC	yes
Ranunculus aquatilis var. aquatilis	LC	yes
Ranunculus bulbosus	LC	yes
Ranunculus circinatus	LC	yes
Ranunculus confervoides	LC	yes
Ranunculus ficaria subsp. ficaria	LC	yes
Ranunculus flammula	LC	yes
Ranunculus glacialis	NT	yes
Ranunculus hyperboreus	LC	yes
Ranunculus lapponicus	LC	yes
Ranunculus lingua	LC	yes
Ranunculus nivalis	LC	yes
Ranunculus peltatus subsp. baudotii	LC	yes
Ranunculus peltatus subsp. peltatus	LC	yes
Ranunculus polyanthemos	LC	yes

Ranunculus pygmaeus	LC	yes
Ranunculus repens	LC	yes
Ranunculus reptabundus	NT	yes
Ranunculus reptans	LC	yes
Ranunculus sceleratus	LC	yes
Ranunculus sulphureus	EN	yes
Raphanus raphanistrum	LC	yes
Rhamnus cathartica	LC	yes
Rhamnus frangula	LC	yes
Rhinanthus angustifolius	LC	yes
Rhinanthus minor subsp. groenlandicus	LC	yes
Rhinanthus minor subsp. minor	LC	yes
Rhodiola rosea	LC	no
Rhododendron lapponicum	NT	yes
Rhynchospora alba	LC	no
Rhynchospora fusca	NT	no
Ribes alpinum	LC	yes
Ribes nigrum	LC	yes
Ribes spicatum	LC	yes
Rorippa amphibia	LC	yes
Rorippa palustris	LC	yes
Rosa acicularis	LC	yes
Rosa caesia	LC	yes
Rosa canina	CR	yes
Rosa dumalis	LC	yes
Rosa majalis	LC	yes
Rosa mollis	LC	yes
Rosa sherardii	EN	yes
Rubus arcticus	LC	yes

Rubus caesius	LC	yes
Rubus chamaemorus	LC	yes
Rubus humulifolius	EX	yes
Rubus idaeus	LC	yes
Rubus saxatilis	LC	yes
Rubus sect. Corylifolii	NT	yes
Rumex acetosa subsp. acetosa	LC	yes
Rumex acetosa subsp. lapponicus	LC	yes
Rumex acetosella subsp. acetosella	LC	yes
Rumex acetosella subsp. tenuifolius	LC	yes
Rumex aquaticus	LC	yes
Rumex crispus	LC	yes
Rumex graminifolius	NT	yes
Rumex hydrolapathum	LC	yes
Rumex longifolius	LC	yes
Rumex maritimus	EN	yes
Rumex pseudonatronatus	LC	yes
Rumex thyrsiflorus	NT	yes
Ruppia cirrhosa	LC	no
Ruppia maritima	NT	no
Sagina maritima	EN	yes
Sagina nivalis	NT	no
Sagina nodosa	LC	yes
Sagina procumbens	LC	yes
Sagina saginoides	LC	yes
Sagittaria natans	LC	no
Sagittaria sagittifolia	LC	no
Salicornia europaea	EN	yes
Salix arbuscula	EN	yes

Salix aurita	LC	yes
Salix caprea	LC	yes
Salix cinerea	LC	yes
Salix glauca	LC	yes
Salix glauca subsp. glauca	LC	yes
Salix glauca subsp. stipulifera	LC	yes
Salix hastata	LC	yes
Salix herbacea	LC	yes
Salix lanata subsp. glandulifera	VU	yes
Salix lanata subsp. lanata	LC	yes
Salix lapponum	LC	yes
Salix myrsinifolia subsp. borealis	LC	yes
Salix myrsinifolia subsp. myrsinifolia	LC	yes
Salix myrsinites	LC	yes
Salix myrtilloides	LC	yes
Salix pentandra	LC	yes
Salix phylicifolia	LC	yes
Salix polaris	LC	yes
Salix pyrolifolia	CR	yes
Salix repens subsp. repens	LC	yes
Salix repens subsp. rosmarinifolia	LC	yes
Salix reticulata	LC	yes
Salix starkeana subsp. cinerascens	LC	yes
Salix starkeana subsp. starkeana	LC	yes
Salix triandra	NT	yes
Salsola kali	EN	no
Samolus valerandi	EN	yes
Sanicula europaea	LC	yes
Satureja acinos	LC	no

Satureja vulgaris	LC	no
Saussurea alpina	LC	no
Saxifraga adscendens	EN	yes
Saxifraga aizoides	LC	yes
Saxifraga cernua	LC	yes
Saxifraga cespitosa	LC	yes
Saxifraga foliolosa	LC	yes
Saxifraga granulata	NT	yes
Saxifraga hirculus	VU	yes
Saxifraga nivalis	LC	yes
Saxifraga oppositifolia	LC	yes
Saxifraga rivularis	LC	yes
Saxifraga stellaris	LC	yes
Saxifraga tenuis	LC	yes
Saxifraga tridactylites	NT	yes
Scheuchzeria palustris	LC	no
Schoenoplectus lacustris	LC	no
Schoenoplectus tabernaemontani	LC	no
Schoenus ferrugineus	EN	yes
Scirpus radicans	EN	yes
Scirpus sylvaticus	LC	yes
Scleranthus annuus	LC	no
Scleranthus perennis	EN	no
Scolochloa festucacea	LC	no
Scorzonera humilis	LC	yes
Scrophularia nodosa	LC	no
Scutellaria galericulata	LC	yes
Scutellaria hastifolia	LC	yes
Sedum acre	LC	yes

Sedum album	LC	yes
Sedum annuum	LC	yes
Sedum rupestre	NT	yes
Sedum sexangulare	LC	yes
Sedum telephium subsp. maximum	LC	yes
Sedum telephium subsp. ruprechtii	LC	yes
Sedum villosum	VU	yes
Selaginella selaginoides	LC	no
Selinum carvifolia	LC	yes
Senecio sylvaticus	LC	yes
Senecio vulgaris	LC	yes
Seseli libanotis	LC	no
Sesleria caerulea	NT	no
Sibbaldia procumbens	LC	no
Silene acaulis	LC	yes
Silene dioica	LC	yes
Silene involucrata subsp. tenella	CR	yes
Silene latifolia subsp. alba	LC	yes
Silene nutans	LC	yes
Silene rupestris	LC	yes
Silene tatarica	VU	yes
Silene uniflora	LC	yes
Silene wahlbergella	NT	yes
Silene viscosa	LC	yes
Silene vulgaris var. litoralis	LC	yes
Silene vulgaris var. vulgaris	LC	yes
Sinapis arvensis	LC	yes
Sisymbrium officinale	LC	yes
Sium latifolium	CR	yes

Solanum dulcamara	LC	yes
Solanum nigrum	LC	yes
Solidago virgaurea	LC	yes
Sonchus arvensis var. arvensis	LC	yes
Sonchus arvensis var. maritimus	LC	yes
Sonchus asper	LC	yes
Sonchus oleraceus	LC	yes
Sorbus aucuparia subsp. aucuparia	LC	yes
Sorbus aucuparia subsp. glabrata	LC	yes
Sorbus hybrida	LC	yes
Sorbus intermedia	VU	yes
Sorbus meinichii	CR	yes
Sparganium angustifolium	LC	yes
Sparganium emersum	LC	yes
Sparganium glomeratum	LC	yes
Sparganium gramineum	LC	yes
Sparganium hyperboreum	LC	yes
Sparganium microcarpum	LC	yes
Sparganium natans	LC	yes
Sparganium neglectum	EX	yes
Spergula arvensis subsp. arvensis	LC	yes
Spergula arvensis subsp. sativa	LC	yes
Spergula morisonii	LC	yes
Spergularia media	CR	yes
Spergularia rubra	LC	yes
Spergularia salina	LC	yes
Spirodela polyrhiza	LC	no
Stachys palustris	LC	yes
Stachys sylvatica	LC	yes

Stellaria alsine	LC	yes
Stellaria borealis	LC	yes
Stellaria crassifolia var. crassifolia	LC	yes
Stellaria crassifolia var. minor	EN	yes
Stellaria fennica	NT	yes
Stellaria graminea	LC	yes
Stellaria holostea	LC	yes
Stellaria humifusa	EX	yes
Stellaria longifolia	LC	yes
Stellaria media	LC	yes
Stellaria nemorum	LC	yes
Stellaria palustris	LC	yes
Stratiotes aloides	LC	no
Suaeda maritima	EN	yes
Subularia aquatica	LC	no
Succisa pratensis	LC	yes
Tanacetum vulgare	LC	yes
Taxus baccata	NT	yes
Thalictrum alpinum	LC	yes
Thalictrum aquilegiifolium	VU	yes
Thalictrum flavum	LC	yes
Thalictrum lucidum	CR	yes
Thalictrum minus subsp. kemense	NT	yes
Thalictrum simplex subsp. boreale	LC	yes
Thalictrum simplex subsp. simplex	VU	yes
Thelypteris palustris	LC	no
Thlaspi arvense	LC	yes
Thymus serpyllum subsp. serpyllum	NT	yes
Thymus serpyllum subsp. tanaensis	LC	yes

Tilia cordata	LC	yes
Tofieldia pusilla	LC	yes
Torilis japonica	VU	yes
Tragopogon pratensis	LC	yes
Trichophorum alpinum	LC	no
Trichophorum cespitosum	LC	no
Trientalis europaea	LC	no
Trifolium arvense	LC	yes
Trifolium aureum	NT	yes
Trifolium fragiferum	NT	yes
Trifolium hybridum	LC	yes
Trifolium medium	LC	yes
Trifolium montanum	NT	yes
Trifolium pratense	LC	yes
Trifolium repens	LC	yes
Trifolium spadiceum	NT	yes
Triglochin maritima	LC	yes
Triglochin palustris	LC	yes
Tripleurospermum inodorum	LC	no
Tripleurospermum maritimum subsp. maritimum	LC	no
Tripleurospermum maritimum subsp. phaeocephalum	LC	no
Tripleurospermum maritimum subsp. subpolare	LC	no
Trisetum spicatum	LC	yes
Trisetum subalpestre	NT	yes
Trollius europaeus	LC	yes
Tussilago farfara	LC	yes
Typha angustifolia	LC	yes

Typha latifolia	LC	yes
Ulmus glabra	VU	yes
Ulmus laevis	VU	yes
Urtica dioica subsp. dioica	LC	yes
Urtica dioica subsp. sondenii	LC	yes
Utricularia australis	LC	no
Utricularia intermedia	LC	no
Utricularia minor	LC	no
Utricularia ochroleuca	LC	no
Utricularia stygia	LC	no
Utricularia vulgaris	LC	no
Vaccinium microcarpum	LC	yes
Vaccinium myrtillus	LC	yes
Vaccinium oxycoccos	LC	yes
Vaccinium uliginosum	LC	yes
Vaccinium vitis.idaea	LC	yes
Vahlodea atropurpurea	LC	no
Valeriana officinalis	LC	yes
Valeriana sambucifolia subsp. salina	LC	yes
Valeriana sambucifolia subsp. sambucifolia	LC	yes
Valerianella locusta	NT	yes
Veratrum album subsp. lobelianum	CR	no
Verbascum nigrum	LC	yes
Verbascum thapsus	LC	yes
Veronica agrestis	LC	yes
Veronica alpina subsp. alpina	LC	yes
Veronica alpina subsp. pumila	VU	yes
Veronica arvensis	LC	yes

Veronica beccabunga	NT	yes
Veronica chamaedrys	LC	yes
Veronica fruticans	NT	yes
Veronica longifolia	LC	yes
Veronica officinalis	LC	yes
Veronica opaca	LC	yes
Veronica scutellata	LC	yes
Veronica serpyllifolia subsp. humifusa	LC	yes
Veronica serpyllifolia subsp. serpyllifolia	LC	yes
Veronica spicata	LC	yes
Veronica verna	LC	yes
Viburnum opulus	LC	yes
Vicia cassubica	EN	yes
Vicia cracca	LC	yes
Vicia hirsuta	LC	yes
Vicia lathyroides	VU	yes
Vicia sepium subsp. montana	LC	yes
Vicia sepium subsp. sepium	LC	yes
Vicia sylvatica	LC	yes
Vicia tetrasperma	LC	yes
Vincetoxicum hirundinaria	LC	yes
Viola arvensis	LC	yes
Viola biflora	LC	yes
Viola canina subsp. canina	LC	yes
Viola canina subsp. montana	LC	yes
Viola collina	EN	yes
Viola epipsila	LC	yes
Viola mirabilis	LC	yes

Viola palustris	LC	yes
Viola persicifolia	EN	yes
Viola reichenbachiana	EN	yes
Viola riviniana	LC	yes
Viola rupestris subsp. relicta	EN	yes
Viola rupestris subsp. rupestris	LC	yes
Viola selkirkii	LC	yes
Viola tricolor var. tricolor	LC	yes

Viola uliginosa	EN	yes
Woodsia alpina	LC	no
Woodsia glabella	NT	no
Woodsia ilvensis	LC	no
Zannichellia major	LC	yes
Zannichellia palustris	LC	yes

CODES USED IN THE THESIS

##########Code for the Environmental Layers #########

```
require("raster")
rasterOptions(maxmemory = 2e+09)
setwd("E:/GIS/Finland/Corine2012_FI_20m")

lu = raster("Corine_20m.tif")
plot(lu)
lu

which
lu[lu == 48] <- NA
plot(lu)
lu

for (i in 47){
    print(i)
    #repl = as.data.frame(cbind(1:48, rep(0, 48)))
    #repl[i,2] = 1
    #landuse = subs(lu, repl)
    #repl[i,2] = 1
    #landuse = subs(lu, repl)
    repl = matrix(c(0,(i-1),0,i,i,1,i,47,0), ncol=3, byrow=T)
    landuse = reclassify(lu, repl)
    print(".")
    landuse = aggregate(landuse, 50)
    print(".")
    writeRaster(landuse, paste("landuse_", i, "_1km.tif", sep
= ""))
    print(".")
}

par(mfrow=c(6,8))
for (i in 1:47)
    plot(raster(paste("landuse_ ", i, " _1km.tif", sep = "")))
```

#################### Stack environmental layers ############################

```
Finaltitude <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/altitude_10km.tif")
Bio1 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_1_10km.tif")
Bio2 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_2_10km.tif")
Bio3 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_3_10km.tif")
Bio4 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_4_10km.tif")
Bio5 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_5_10km.tif")
```

```
Bio6 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_6_10km.tif")
Bio7 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_7_10km.tif")
Bio8 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_8_10km.tif")
Bio9 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_9_10km.tif")
Bio10 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_10_10km.tif")
Bio11 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_11_10km.tif")
Bio12 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_12_10km.tif")
Bio13 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_13_10km.tif")
Bio14 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_14_10km.tif")
Bio15 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_15_10km.tif")
Bio16 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_16_10km.tif")
Bio17 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_17_10km.tif")
Bio18 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_18_10km.tif")
Bio19 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/bio_19_10km.tif")
Land1 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_1_10km.tif")
Land2 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_2_10km.tif")
Land3 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_3_10km.tif")
Land4 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_4_10km.tif")
Land5 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_5_10km.tif")
Land6 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_6_10km.tif")
Land7 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_7_10km.tif")
Land8 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_8_10km.tif")
Land9 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_9_10km.tif")
Land10 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_10_10km.tif")
Land11 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_11_10km.tif")
```

```
Land12 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_12_10km.tif")
Land13 <- raster("C:/Users/jrikberg/Species
Distribution/GISFinland/10 km data/landuse_13_10km.tif")

sigFinland <- stack(Finaltitude, Bio1, Bio2, Bio3, Bio4, Bio5,
Bio6, Bio7, Bio8, Bio9, Bio10, Bio11, Bio12, Bio13, Bio14,
Bio15, Bio16, Bio17, Bio18, Bio19, Land1, Land2, Land3, Land4,
Land5, Land6, Land7, Land8, Land9, Land10, Land11, Land12,
Land13)
```

######### Simulation and mapping of Kastikka-species ####################

#alltest = filename, consists of three columns: species names, North and South coordinates

```
class(alltest)
alltest=as.data.frame(alltest) #making the species list a dataframe
names <- as.vector(unique(alltest[,1])) #unique values from the first
column = species names
names

sigPCA = raster.reduce(sigFinland, n = 3) #sigFinland =
stacked environmental data
maxcells = 3393*.65 ##if is present in over 65% f the squares =>map, if under 65%
=> model

modeloption=c()
for(i in names){ #for every name (species) the code runs once
  spData = alltest[alltest[,1]==i,]
  spData = spData[,-1] ##removes the names
  if(nrow(spData) < maxcells){
    spMap = map.sdm(spData, sigPCA, runs = 10) #for species present in
under 65 % of the cells => model
    modeloption[i] = nrow(spData)
  } else {
    spMap = map.points(spData, sigPCA) #for species present in over 65 %
of the cells => map
    modeloption[i] = nrow(spData)
  }
  cat(i, "-", modeloption[i])
  print("/n")
  writeRaster(spMap[[1]], filename = i, format = "GTiff",
overwrite=TRUE)
  map.draw(layer = spMap[[1]], spName = i, print = TRUE)
}
```

################ Mapping of the threatened species (SYKE) ############

#Syke = file containein species names and coordinates

```
class(Syke)
Syke=as.data.frame(Syke)


snames <- unique(Syke[,1]) #unique values from the first column = species names
snames

for(i in snames){
  print(i)
  spData = Syke[Syke[,1]==i,]
  spData = spData[,-1] ##removes the names
  distrRaw <- map.points(spData, sigFinland, eval = TRUE)
  distrRaw
  dev.off()
  raster::plot(distrRaw[[1]])
  writeRaster(distrRaw[[1]], filename = i, format = "GTiff",
overwrite=TRUE)
  map.draw(layer = distrRaw[[1]], spName = i, print = TRUE)
}
```

##############Taxonomic Diversity and Red List Index##############

#Mapping all species into one map

```
redlistsp <-
list.files(path="//ATKK/home/j/jrikberg/Documents/Master
Thesis Rikberg/Thesis Data/Species Distribution/120917 Final
SYKE Maps", pattern = "tif$", full.names = TRUE)

redlistsp <- raster::stack(redlistsp)
redlistsp <-spp[[order(names(spp))]]
dim(redlistp) #the third dimension is the number of species (1194)
plot(redlistsp)
plot(sum(redlistsp))

spRichMap <- sum(redlistsp)
plot(spRichMap)
```

calculate spearman correlations and p-values for the correlations between taxonomic diversity and environmental variables used in the species distribution modelling

```
for(i in 1:dim(sigFinland)[3]){
  resTest = cor.test(as.vector(spRichMap),
as.vector(sigFinland[[i]]), method="spearman",
alternative="two.sided", exact = F)
  print(resTest)
}
```

#Mapping all threatened species into one map

```
threatsp <-
list.files(path="C:/Users/jonri/Documents/Studier/Gradu/Data/t
hesisdata/24112017 Threatened species/120917 Final SYKE Maps",
pattern = "tif$", full.names = TRUE)
threatsp <- raster::stack(threatsp)
plot(sum(threatsp))
redlistsp
ThreatMap <- sum(threatsp)

plot(ThreatMap)
```

calculate p-values and spearman correlations between threatened species and environmental variables used in the species distribution modelling

```
for(i in 1:dim(sigFinland)[3]){
  resTest = cor.test(as.vector(ThreatMap),
as.vector(sigFinland[[i]]), method="spearman",
alternative="two.sided", exact = F)
  print(resTest)
}
```

Taxonomic Diversity - calcultaing the RLI (based on the Finnish Red list 2010) for each cell and making a map out of it

```
library(vegan)
library(ape)
library(cluster)
library(raster)
library(readxl)
library(stats)
library(dendroextras)
library(BAT)
library(red)
library(readxl)
library(sp)

allsp <-1194
nsp = allsp #number of species in the analysing process
```

Import the RLI data (species names and Red List Index)

```
taxrli <- read_excel("//atkk/home/j/jrikberg/Documents/Master
Thesis Rikberg/Thesis Data/Red List 2010/0910 RLI.xlsx")
taxrli<-as.data.frame(taxrli)
taxrli<-taxrli[1:nsp,]
rlinames <- taxrli$Species
taxrli=taxrli[,-1, drop=F]
rownames(taxrli) <- rlinames
rlinames
```

```
taxrli<-taxrli[order(rownames(taxrli)),,drop=F]
```
#let's order the variables.

#Convert numerical data to string

```
taxrli[taxrli$`RLI 2010` == 5,]   <- "EX"
taxrli[taxrli$`RLI 2010` == 4,]   <- "CR"
taxrli[taxrli$`RLI 2010` == 3,]   <- "EN"
taxrli[taxrli$`RLI 2010` == 2,]   <- "VU"
taxrli[taxrli$`RLI 2010` == 1,]   <- "NT"
taxrli[taxrli$`RLI 2010` == 0,]   <- "LC"
taxrli[is.na(taxrli$`RLI 2010`),] <- "DD"
```

#open all Species Distribution Maps (raster files) and stack them together

```
allfiles <- list.files(path="C:/HY-Data/JRIKBERG/290917 All
maps", pattern = "tif$", full.names = TRUE)
spp <- raster::stack(allfiles[1:nsp])
spp<-spp[[order(names(spp))]]
dim(spp)
```
#the third dimension is the number of species (1194)

```
plot(spp)

any(!names(spp) == row.names(taxrli))
```
#are species in the same order? if yes, it should be FALSE

#filter the raster files so that you only have the species with RLI data

```
rownames(taxrli)[which(!rownames(taxrli)%in%names(spp))] #all
species match (code gives list of those species that are
present in the RLI file but not present in the maps (spp))
finalRLI <- spp[[which(names(spp)%in%rownames(taxrli))]]
```
#stack all matching species into one object

```
plot(finalRLI)
dim(finalRLI))
```
third dimension = number of species (1194)

#map of species richness across Finland

```
plot(sum(finalRLI))
```

#convert to 3D array

```
tmaps = as.array(finalRLI)
dimnames(tmaps)[[3]] <- names(finalRLI)
tmaps
```

#get data for each cell (row by row) => which species are present / absent in each cell

```
tcells = matrix(NA, 0, ncol=nsp) # ncol = 1194 (amount of
species)
for (r in 1:nrow(tmaps)){ #for every cell in row 1
  cat("row", r, "of", nrow(tmaps))
  for(c in 1:ncol(tmaps)){ #for every cell in column 1
    tcells = rbind(tcells, tmaps[r,c,])
    cat(".")
  }
```

```
  cat("\n")
}

colnames(tcells) = names(tmaps)
tcells
```

Red List Index value for each cell in the grid

```
rliCell = c()
for (i in 1:nrow(tcells)){
  rliNA <- ifelse(tcells[i,] == 1, taxrli$`RLI 2010`, NA)
  rliCell = c(rliCell, rli(rliNA))
}
rliCell
```

#create RLI map

```
rliMap = raster(matrix(rliCell, nrow = nrow(spp), byrow = T))
plot(rliMap)

hist(rliCell)
```

#null model for expected RLI per cell if species were randomly distributed accross Finland, keeping AOO and rli value of each species, they just move around randomly

```
runs = 999
expRli = matrix(NA, nrow = nrow(tcells), ncol = runs)
for(r in 1:runs){
  cat("Run",r,"of",runs,"\n")
  runCells = tcells
  for(i in 1:ncol(runCells))
    runCells[!is.na(runCells[,i]),i] <-
sample(runCells[!is.na(runCells[,i]),i])
  for (i in 1:nrow(expRli)){
    if(is.na(runCells[i,1])){
      expRli[i,r] <- NA
    } else {
      expRli[i,r] <- rli(taxrli$`RLI 2010`[runCells[i,]==1])
    }
  }
}
colSums(expRli, na.rm=T)
expRliMap = raster(matrix(rowMeans(expRli), nrow = nrow(spp),
byrow = T))
plot(expRliMap)
```

#map of expected RLI if there was no difference in RLI between cells

```
expRliMap = raster(matrix(rowMeans(expRli), nrow = nrow(spp),
byrow = T))
plot(expRliMap)
```

#map of difference between observed and expected

```
diffRliMap = rliMap-expRliMap
```

```
plot(diffRliMap)
```

#Effect Size (0 to 1, based on ranks)

```
percentile = c()
for(i in 1:nrow(tcells)){
  if(!anyNA(tcells[i,])){
    percentile[i] = rank(c(rliCell[i], expRli[i,]),
ties.method = "average")[1]/1000
  } else {
    percentile[i] = NA
  }
}

sesRliMap = raster(matrix(percentile, nrow = nrow(spp), byrow
= T))
plot(sesRliMap)
sesRliMap
```

#correlations for environmental layers

```
for(i in 1:dim(sigFinland)[3]){
  cat(cor(as.vector(sesRliMap), as.vector(sigFinland[[i]]),
use="complete.obs")) ##ONE LAYER AT A TIME!
  cat("\n")
}
```

#Effect Size (0 to 1, based on ranks)

```
percentile = c()
for(i in 1:nrow(cells)){
  if(!anyNA(cells[i,])){
    percentile[i] = rank(c(fRliCell[i], expFRli[i,]),
ties.method = "average")[1]/(nruns+1)
  } else {
    percentile[i] = NA
  }
}
sesFRliMap = raster(matrix(percentile, nrow = nrow(spp), byrow
= T))
plot(sesFRliMap)
```

############## Functional Diversity ################

Create Functional Tree of the functional trait data

```
traits <- read_excel("//atkk/home/j/jrikberg/Documents/Master
Thesis Rikberg/Thesis Data/Traits Data/All
Traits/Original/0610_traits_underscores.xlsx")
traits
nrow(traits)
```

```
spnames <- traits$Species
traits=traits[,-1]
rownames(traits) <- spnames

fdist = daisy(traits, "gower", weights =
c(1,1,1,1,1,0.5,0.5,rep(0.125,8))) #different weights for the
traits
functree=hclust(fdist, "average")
plot(as.dendrogram(functree))
```

#open all Species Distribution Maps (raster files) and stack them together

```
allfiles <- list.files(path="C:/HY-Data/JRIKBERG/290917 All
maps", pattern = "tif$", full.names = TRUE)
ssp <- raster::stack(allfiles)
dim(ssp)
plot(ssp)
```

#filter the raster files so that you only have the species with functional trait data

```
names(ssp)
rownames(traits)
rownames(traits)[which(!rownames(traits)%in%names(ssp))] #all
```

species match (code gives list of those species that are present in the traits file but not present in the maps (ssp))

```
finalMaps <- ssp[[which(names(ssp)%in%rownames(traits))]]
#stack all matching species into one object

plot(finalMaps)
dim(finalMaps)
```

#convert to 3D array

```
fmaps = as.array(finalMaps)
dimnames(fmaps)[[3]] <- names(finalMaps)
fmaps
```

#get data for each cell (row by row) => which species are present / absent in each cell

```
cells = matrix(NA, 0, 971) # ncol = 971 (amount of species)
for (r in 1:nrow(fmaps)){ #for every cell in row 1
  cat("row", r, "of", nrow(fmaps))
  for(c in 1:ncol(fmaps)){ #for every cell in column 1
    cells = rbind(cells, fmaps[r,c,])
    cat(".")
  }
  cat("\n")
}

colnames(cells) = names(finalMaps) #I had fmaps before, but
changed it to finalMaps
cells
```

 # calculate Functional Diversity of each cell

```
fd = c()
for (i in 1:nrow(cells))
  fd = c(fd, alpha(cells[i,], functree))
fd
```

 # Create a map of the Functional Diversity (FD)

```
funcmap = raster(matrix(fd, nrow = nrow(finalMaps), byrow =
T))
plot(funcmap)
funcmap
writeRaster(sesmap2, "funcmap", format = "GTiff")
```

 # calculate p-values for the correlations between FD and environmental variables used in the species distribution modelling

```
for(i in 1:dim(sigFinland)[3]){
  cat(cor.test(as.vector(funcmap), as.vector(sigFinland[[i]]),
method="spearman", alternative = "two.sided", exact = F))
  cat("\n")
}
```

 # null model for expected FD per cell

```
nruns = 100
expfd = matrix(NA, nrow = nrow(cells), ncol = nruns)
for(c in 1:nrow(cells)){
  cat("\n",c, "of", nrow(cells))
  if(is.na(sum(cells[c,])))
    next
  for(r in 1:nruns){
    cat(".")
    expfd[c,r] = alpha(sample(cells[c,]), functree)
  }
}
```

 # map of expected FD if there was no difference in trees between cells

```
expmap = raster(matrix(rowMeans(expFD), nrow =
nrow(finalMaps), byrow = T))
plot(expmap)
writeRaster(sesmap2, "expmap", format = "GTiff")
```

 # map of difference between observed and expected FD

```
diffmap = funcmap-expmap
plot(diffmap)
writeRaster(sesmap2, "Diffmap", format = "GTiff")
```

#Effect Size (0 to 1, based on ranks)

```
percentile = c()
for(i in 1:nrow(cells))
  percentile[i] = rank(c(fd[i], expFD[i,]), ties.method =
"average")[1]/1000
sesmap = raster(matrix(percentile, nrow = nrow(ssp), byrow =
T))
plot(sesmap)

sesmap2=mask(sesmap, funcmap)
plot(sesmap2)
```